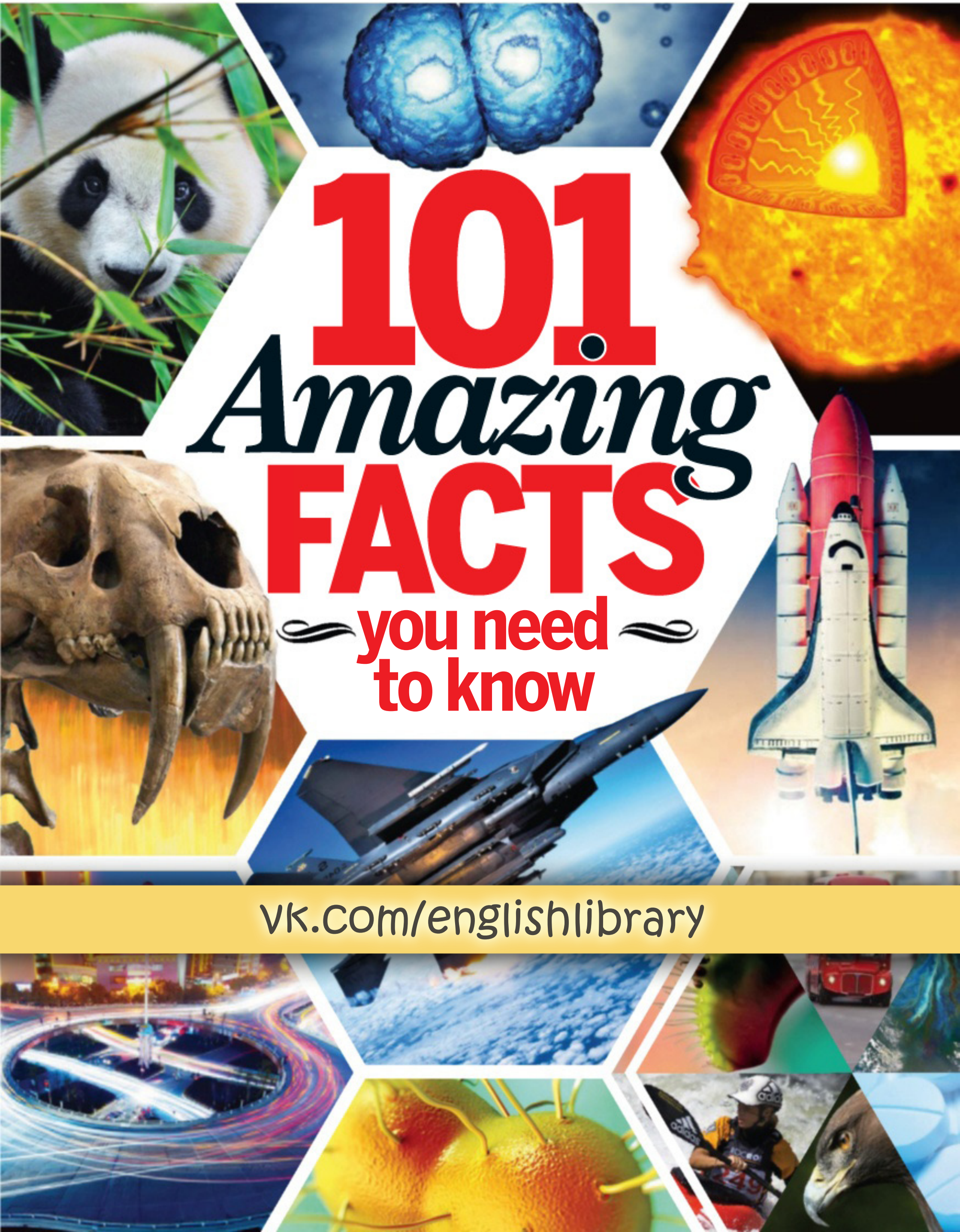
HOW IT WORKS

101 Amazing FACTS you need to know



Welcome to

101 Amazing FACTS you need to know

Have you ever wondered why we sneeze? How about how pearls are formed? If you want to know more about the world we live in, you've come to the right place. This book contains facts from six subject areas: the environment, technology, science, space, transport and history – and each section is packed with questions and answers that will feed even the hungriest of minds.

101 Amazing FACTS you need to know

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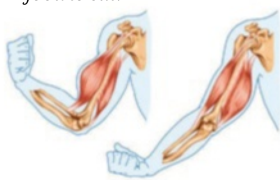


Space

Transport

History

How does the Arctic Ocean freeze?

It's difficult to imagine such a huge expanse of water freezing solid, so how is it possible?

© Science Photo Library

© Nasa

Arctic sea ice is that which forms on the Arctic Ocean during the winter months. Pure water, which contains no other molecules, substances or impurities, freezes at 0 degrees Celsius (32 degrees Fahrenheit). The world's seawater, on the other hand, contains around 3.5 per cent dissolved minerals and salts. This additional material lowers the freezing point of the seawater to around -2 degrees Celsius (28.4 degrees Fahrenheit) because the freezing point depends on the number of molecules present in a solution, as well as the type of molecule(s). During the winter months, when the air temperature in the Arctic starts to fall dramatically, a deep layer of seawater begins to develop minuscule ice crystals; this slushy water is called frazil ice. A further drop in temperature causes the frazil ice to thicken. Pockets of salty slush accumulate until they become so heavy they start to sink. This leaves the top layer of icy crystals with significantly less salt content. The freezing point of this surface water therefore becomes higher and the falling temperatures enable the crystals to solidify into pack ice. This pack ice grows to become one huge floating sheet (made up of many smaller floes), the thickness and coverage of which varies over the year, but reaches its peak in March. During the warmer summer months, meanwhile, the ice begins to retreat and break up, reaching its lowest extent around September.

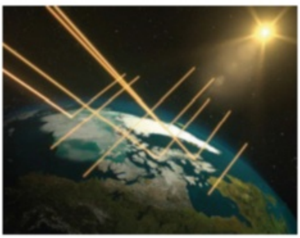
Inset, left
A satellite shot of sea ice floes and icebergs off the coast of Antarctica

Understanding how polar ice affects the world climate

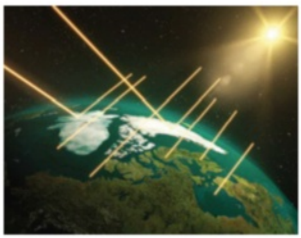
Sea ice at the poles is important because it influences the weather across the entire planet. The ice acts like a mirror, deflecting the Sun's rays back into the atmosphere. As the ice melts, more of the 'dark' ocean beneath, capable of absorbing the Sun's heat, is exposed. When the Arctic is frozen, warmer water entering from the Pacific or Atlantic begins to cool, becoming dense and sinking. This displacement of water drives the circulation of Earth's oceans, affecting weather and conditions throughout the world. So, in many respects, the amount and extent of Arctic sea ice is absolutely critical to the global climate.

3x © Nasa

High reflection
The white sea ice cover acts like a mirror, reflecting the Sun's rays back out to space, preventing the sea from heating excessively.



Sea exposed
As the ice melts, there is more dark seawater to absorb sunlight, which further melts the ice.



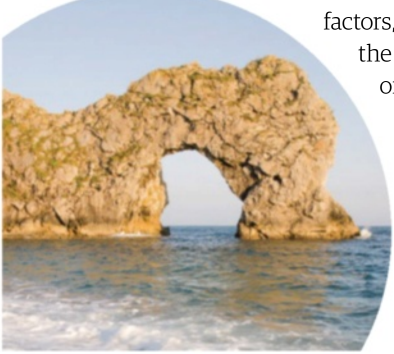
Low reflection
The more sunlight absorbed by the seawater, the more the ice melts until, eventually, significantly less light is reflected back into space.

Why is the coast eroding?

Learn about the amazing processes that are building and breaking our shores right now...

Water is not given enough credit for the role it plays in shaping Earth. Tectonic plates and volcanic eruptions are often cited as the culprits for most land features, but it is water and wave action that shapes our world's coastlines. When a wave crashes on the shore it carries sediments that are suspended in the water, and it pushes larger sediments along the ground too. When a wave recedes it also takes sediment with it, but rarely at an equal rate. If a wave deposits more sediment than it takes away then this sediment builds up, causing coastlines to extend. Conversely, when more sediment is being removed than added, the coastline recedes or erodes. Coastal erosion is responsible for some of the most amazing landforms we know today, from the Twelve Apostles in Australia to the White Cliffs of Dover in England. The type of coastline that is created from erosion varies greatly depending on any number of factors, including the strength of the wave action and wind, the sediment composition of the coastline and the types of nearby rock. Coastal erosion is a very slow process, taking hundreds of years, but scientists believe that climate change is speeding things up. Climate change has caused a rise in sea levels and storm frequency and severity – both of which play a key role in erosion. Indeed, the UK's Environment Agency estimates that the British coastline could erode from 67-175 metres (220-575 feet) over the next 100 years.

Below
The arch Durdle Door in Dorset, UK, is one of the most photographed features on the Jurassic Coast

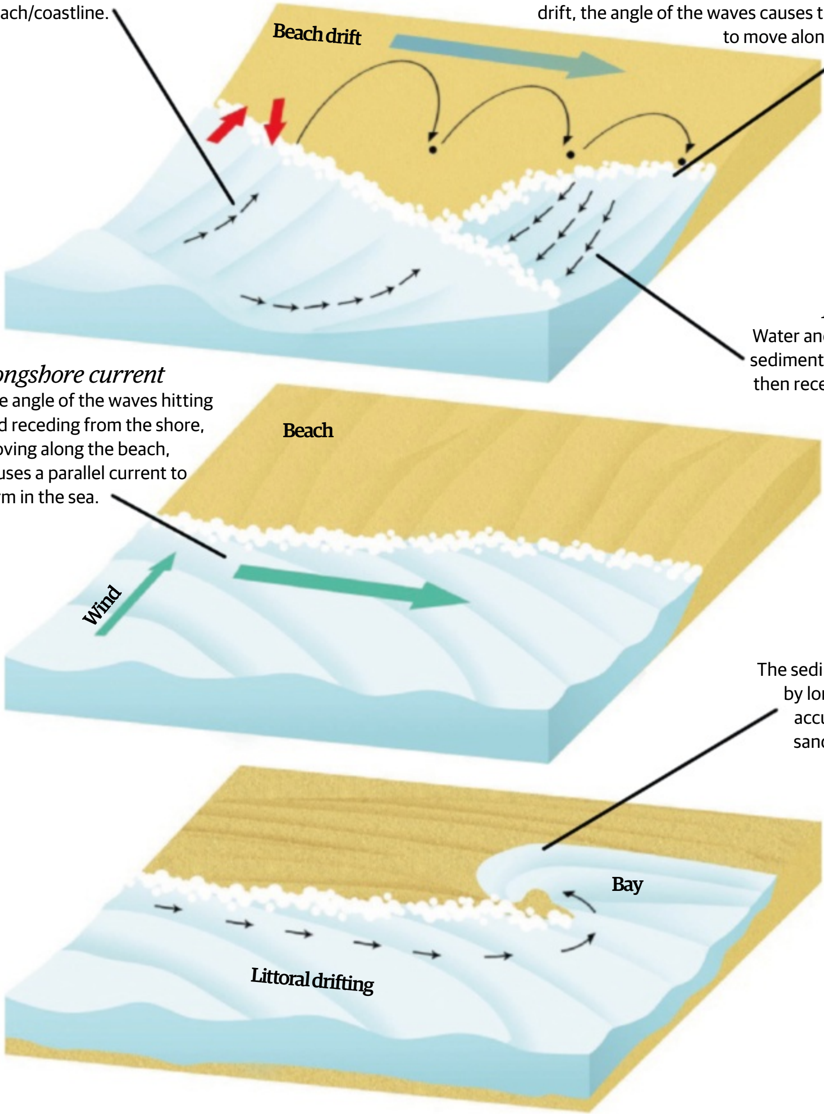


Longshore drift currents explained

Longshore drift occurs when waves crash at an angle and flow back at a right angle

Swash
Water and suspended sediment from a wave washes up onto the beach/coastline.

Sediment
Sediment is washed ashore and pulled back into the ocean at differing rates. During a longshore drift, the angle of the waves causes the sediment to move along the beach.



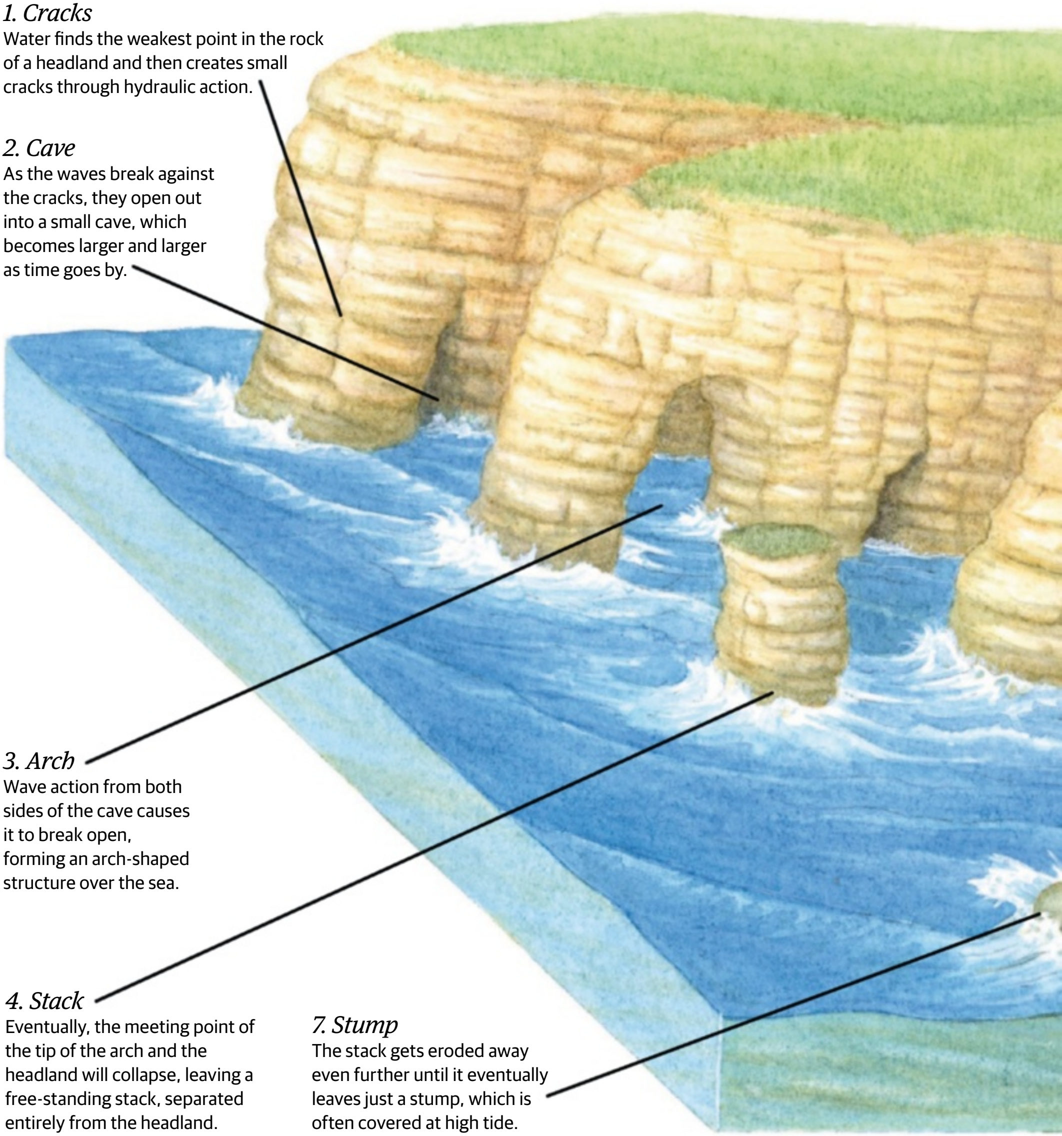
Backwash
Water and suspended sediment from a wave then recede back into the ocean.

Longshore current
The angle of the waves hitting and receding from the shore, moving along the beach, causes a parallel current to form in the sea.

Sand spit
The sediment carried by longshore drift accumulates in a sandbar fashion.

Sea stack formation

Discover how these rocky towers develop and what fate awaits them in the long term...



1. Cracks
Water finds the weakest point in the rock of a headland and then creates small cracks through hydraulic action.

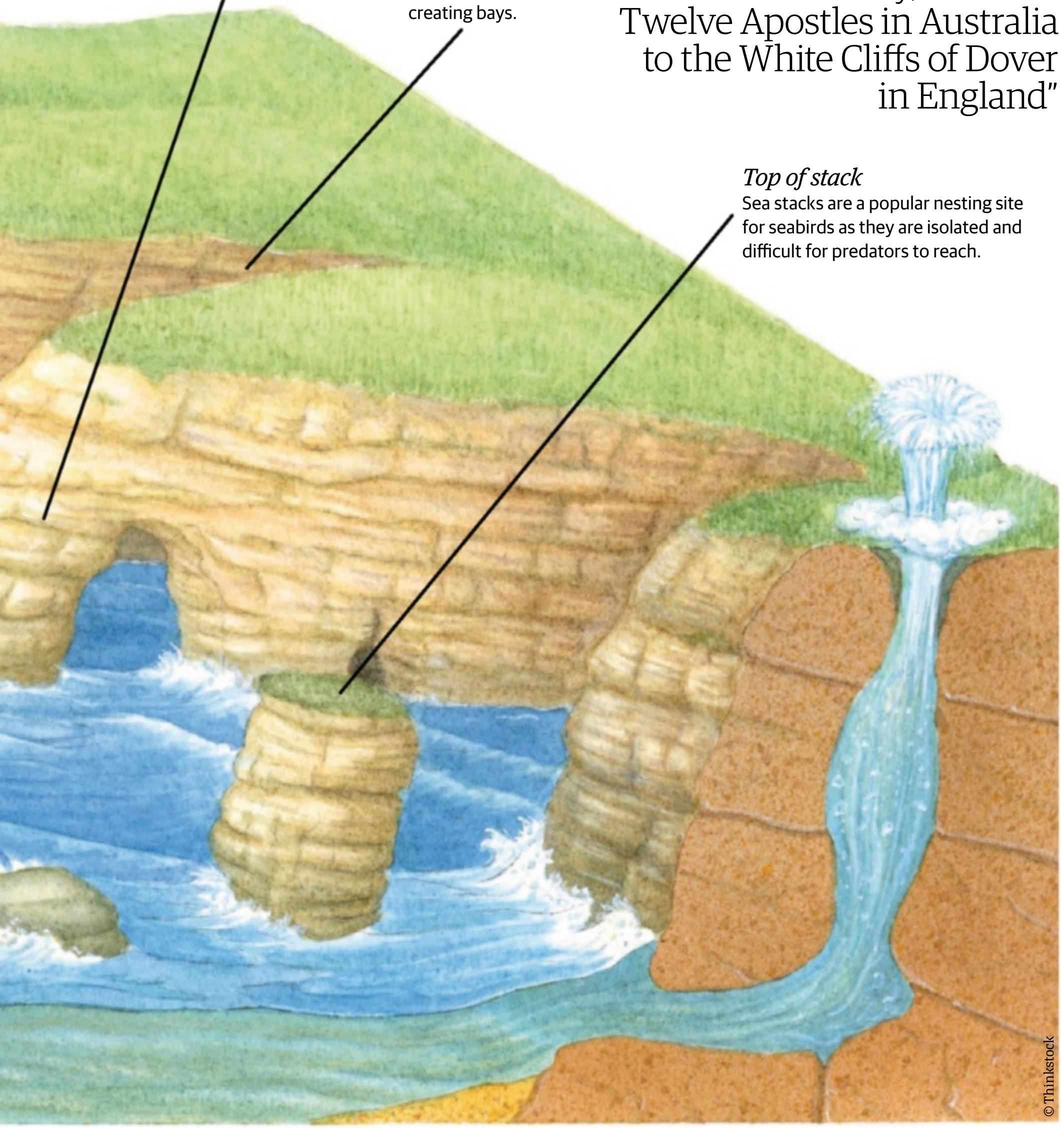
2. Cave
As the waves break against the cracks, they open out into a small cave, which becomes larger and larger as time goes by.

3. Arch
Wave action from both sides of the cave causes it to break open, forming an arch-shaped structure over the sea.

4. Stack
Eventually, the meeting point of the tip of the arch and the headland will collapse, leaving a free-standing stack, separated entirely from the headland.

7. Stump
The stack gets eroded away even further until it eventually leaves just a stump, which is often covered at high tide.

"Coastal erosion is responsible for some of the most amazing landforms we know today, from the Twelve Apostles in Australia to the White Cliffs of Dover in England"



What is coral?

Is it animal, vegetable or mineral?

Left
Coral can be home to a huge number of marine organisms

While corals may look like rocks and share several characteristics of plants, they are in fact animals. To be exact they are aquatic marine invertebrates (known as polyps) that live in the warm shallows of the clear coastal waters located around the world. A huge number of marine organisms make their home among the corals, making reefs some of the most abundant and varied habitats on Earth. Because the nutrients on which plankton need to feed dissolve better in deeper, cooler water, the warmer layers become a less attractive spot for the huge numbers of floating plankton to occupy. Therefore, the upper shallows remain warm and clear – the ideal living conditions for microscopic algae, which use sunlight to combine carbon dioxide and water to create their own food source, which they share with their coral.

Corals live in partnership with single-celled zooxanthellae algae, which are also responsible for the bright colours. If the algae die the coral will turn white, a damaging effect known as coral bleaching. Like jellyfish, corals are cnidarians, except they are rooted to the spot by a tube attached to a surface (usually rock), rather than floating freely like jellyfish. Cnidarians consist of a simple body, featuring a central mouth opening that is surrounded by stinging tentacles. The coral polyp is the soft individual organism that forms from a single-celled alga and lives within a larger community of similar polyps called a colony. They use calcium and a variety of other minerals in the seawater – together with the food waste they produce – to construct their own protective calcium carbonate skeleton shelters in which to live. When coral dies, the hard, chalky skeletal remains are left behind and new polyps will grow on top of these. Sedimentary limestone rock is formed when the coral skeletons are compacted over many thousands of years. Over hundreds of thousands of years, a colony of polyps can grow big enough to link up with other colonies to form a large coral reef.

How do seahorses reproduce?

Discover what makes this equine marine creature so unusual

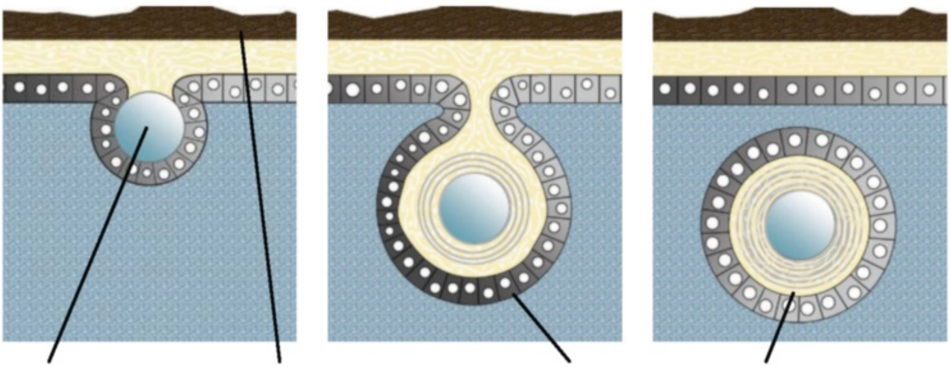
Usually found in the shallows of warm coastal areas, the seahorse is a breed of bony fish that mates for life. They swim upright and have a distinctly horse-like appearance, hence their name. Amazingly, it's the male of this species that bears the young. The female deposits her eggs into the male's brood pouch on its ventral side, which he then fertilises internally. The eggs later hatch into tiny seahorses inside this pouch.

How do pearls form?

How does a speck of dirt turn into a precious gem?

Pearls develop inside molluscs – including oysters, mussels and clams – whenever a foreign particle enters its shell and irritates the soft inner tissues. If the animal can't expel the irritant, it will engage a unique defence mechanism. To protect itself from the particle, the mollusc produces a substance called nacre, or mother-of-pearl, which also lines the inner surface of the creature's shell. Layer upon layer of the hard crystalline nacre is then used to smother the invading object so it cannot harm or contaminate the mollusc. A pearl's iridescent appearance is due to the many layers of nacre that consist of many microscopic crystals. The thickness of one layer of calcium carbonate plates is similar to the wavelength of visible light. Some of the light passing through the top layer of nacre will be reflected, but some will continue to travel through to the bottom layer where further light is reflected. Multiple reflections interfere with each other at different wavelengths, causing colours to be reflected and scattered in all directions, creating an iridescent finish.

Creating a pearl



Irritant
If an invading microbe or grain of dirt infiltrates the shell, the mollusc will defend itself.

Shell
Cells in the shell's outer mantle enable the mollusc to expand as the creature grows.

Epithelial cells
A 'pearl sac' of epithelial cells forms around the irritant. This sac secretes a smooth, crystalline substance called nacre.

Nacre
Layer upon layer of the calcium carbonate-based nacre builds up to protect the mollusc, and eventually form a pearl.


© Nasa
© Science Photo Library

What causes red tides?

Why crimson seas are not as unbelievable a sight as you might first think…

Left
Despite the startling appearance of a sea turned red, many algal blooms are actually harmless

Inset, left
A satellite shot of an algal bloom off the coast of Patagonia, showing the large scale that they can reach

A red tide is the rapid accumulation of a mass of aquatic algae made up of mobile single-celled micro-organisms known as dinoflagellates – which means 'whirling whip' due to the nature of the tail-like projections that propel them through the water. The algae grows, or blooms, more rapidly than usual in order to consume nutrients that have suddenly risen up from the colder depths of the ocean below. The red hue is down to the presence of a certain species of dinoflagellate, or phytoplankton. Together with the more abundant diatom algae, dinoflagellates make up the majority of ocean plankton. Despite the rather startling appearance of a sea that has been turned red, many algal blooms are actually completely harmless. However, you shouldn't consume seafood following a red tide as certain phytoplankton can release harmful substances into the water. Some dinoflagellates can produce toxins when eaten by other creatures and the harmful substances then concentrate inside the creatures that feed on them, and subsequently any humans who go on to dine on the contaminated seafood. The billions of microscopic dinoflagellates in a red tide can also cause spectacular bioluminescence at night. One species in particular – the lingulodinium polyedrum – can create its own light from within. When the organism is jostled or collides with something in the ocean, a chemical reaction occurs when an enzyme called luciferase and a substrate called luciferin, both contained within the organism, combine. This is the catalyst for a chemical reaction that releases a flash of blue light. When this occurs millions of times simultaneously, the effect is quite remarkable for onlookers.

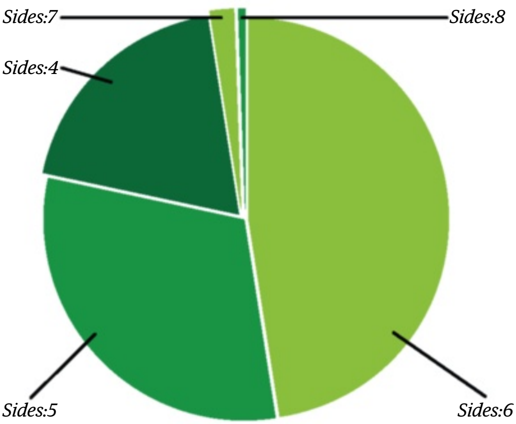
How was the Giant's Causeway formed?

Discover the origins of this geological phenomenon in Northern Ireland

On the north-east coast of County Antrim in Northern Ireland lies an unusual rock formation which draws in millions of visitors from around the world every year. They flock to see a vast plateau of polygonal basalt columns – which are commonly known as the Giant's Causeway – which looks like a carpet of enormous stepping stones extending out into the Irish Sea. The basalt pillars that make up this amazing rock formation dramatically range in size from a matter of centimetres to several metres high. Although the Giant's Causeway is so-named due to an ancient legend, its formation actually began up to 65 million years ago during the Tertiary period when volcanic activity forced tectonic plates to stretch and break. This caused magma to spew up from inside the Earth and spill out across the surface as lava. The temperature of erupting lava can range from between 700 and 1,200 degrees Celsius (1,292 and 2,192 degrees Fahrenheit). However, upon contact with the surface it will immediately begin to cool. At first this cooling is extremely rapid and this results in a hardened crust forming on top of the superhot substance, which

Polygonal pillars of rock

Though the number of sides to each pillar varies, of the 38,000 basalt columns the majority are hexagonal



Above
The Giant's Causeway has become a popular tourist attraction

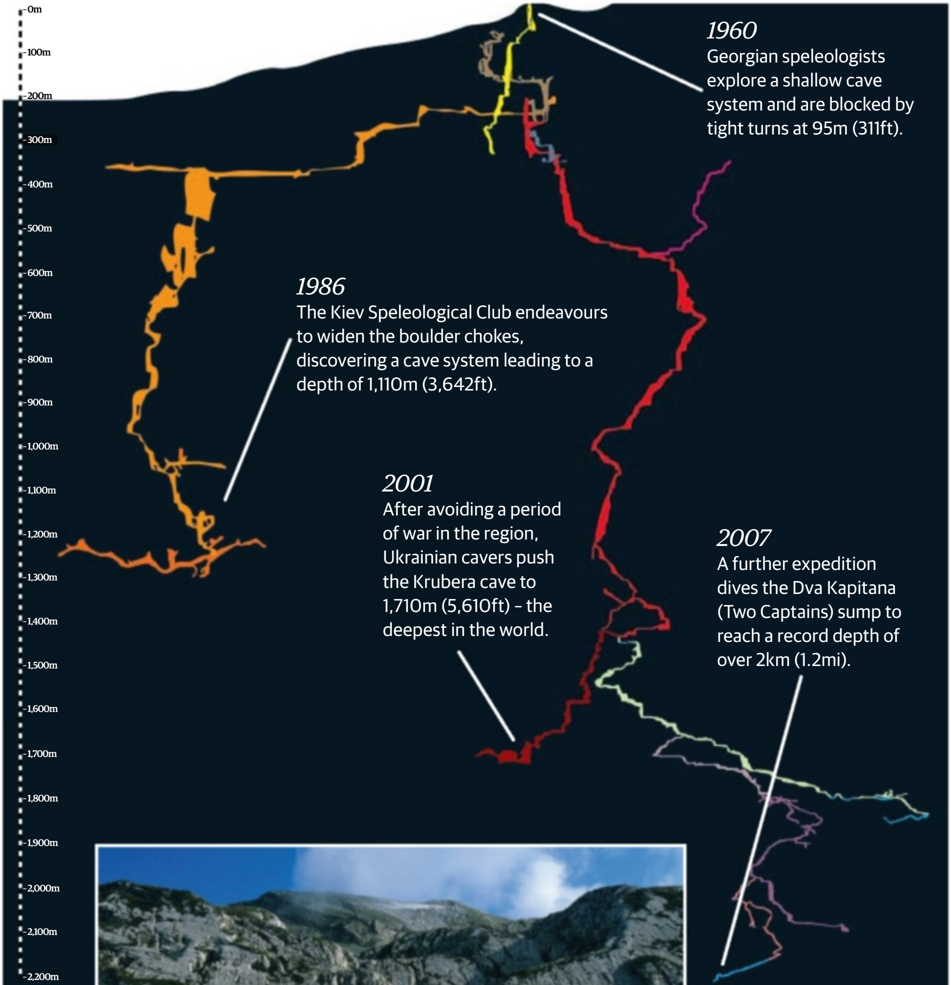
insulates the still liquid lava below. Because the lava is now insulated the cooling becomes increasingly slow over time. While you could probably walk on the crust after just half an hour or so, thick lava flows can take a number of years to cool completely and solidify all the way through. While the temperature falls the lava begins to dry out, and it's this drying that causes the solidifying lava to crack and form regular pillars of basalt rock. The size and shape of each column is ultimately determined by the rate at which the lava actually cools and dries, and therefore the speed at which what's called the 'drying front' moves. Scientists from the University of Toronto discovered that the slower the cooling rate the larger the basalt columns that formed.

How deep is the deepest cave?

Where is the planet's deepest subterranean network and what have cavers found?

In 2007, a team of 41 cavers worked their way into the limestone of the Arabika Massif in the Western Caucasus, Georgia, to descend to new depths of the Voronja Krubera cave system. Two branches of this subterranean warren were discovered to reach 1,775 metres (5,823 feet) and 1,920 metres (6,299 feet), but the deepest point – a sump dubbed 'Two Captains' – exceeded the two-kilometre (1.2-mile) mark to become the deepest natural cave in the world at 2,191 metres (7,188 feet). Essential kit used for casual spelunking (or potholing) includes a hard hat, headlamp, waterproofs, thermals, climbing gear and basic rations for longer expeditions. But the 2007 Krubera caving trip was comprised of professional spelunkers, known as speleologists, who weren't just experienced at exploring caves but specialists in cave sciences including biology, hydrology and geology. The 41 team members spent a total of 29 days mapping out the cave network, as well as recording the temperature and sampling sediments, micro-organisms and speleothems (which include cave formations such as stalagmites). So as well as standard camping gear, sample containers and more unusual scientific devices such as ground-penetrating radar were used to help plan the best possible route ahead. Georgia (specifically the disputed region of Abkhazia) is home to the top three deepest caves on Earth and, incredibly, Two Captains is known to go deeperstill. Ropes and carabiners in the hands of expert climbers are essential for exploring these incredible depths, as the Voronja-Krubera system includes drops like the Big Cascade, which alone plummets 152 metres (499 feet).

How deep is the deepest cave?



1960
Georgian speleologists explore a shallow cave system and are blocked by tight turns at 95m (311ft).

1986
The Kiev Speleological Club endeavours to widen the boulder chokes, discovering a cave system leading to a depth of 1,110m (3,642ft).

2001
After avoiding a period of war in the region, Ukrainian cavers push the Krubera cave to 1,710m (5,610ft) – the deepest in the world.

2007
A further expedition dives the Dva Kapitana (Two Captains) sump to reach a record depth of over 2km (1.2mi).

Left
The Arabika Massif is one of the largest limestone karsts in the Western Caucasus

How do jet streams work?

They're a vital component in regulating global weather, but what do jet streams actually do?

Jet streams are currents of fast-moving air that can be found high in the atmosphere of some planets. Here on Earth, when we refer to 'the jet stream', we're typically talking about either of the polar jet streams. There are also weaker, subtropical jet streams located higher up in the atmosphere, but their altitude means they have less of an effect on commercial air traffic and the weather systems in more populated areas. The northern jet stream travels at about 161-322 kilometres (100-200 miles) per hour from west to east, ten kilometres (six miles) above the surface in a region of the atmosphere that is known as the tropopause (the border between the troposphere and the stratosphere).

It's created by a combination of our planet's rotation, atmospheric heating from the Sun and the Earth's own heat from its core creating temperature differences and, therefore, pressure gradients along which air rushes. In the northern hemisphere, the position of the jet stream can affect the weather by bringing in or pushing away the cold air from the poles. Generally, if it moves south, the weather can turn rather wet and windy; too far south and it will become much colder than usual. The reverse is true if the jet stream moves north, inducing drier and hotter weather than average as warm air moves in from the south. In the southern hemisphere, meanwhile, the jet stream tends to be weakened by a smaller temperature contrast created by the greater expanse of flat, even ocean surface. However, on occasion it can also impact the weather in the same way as the northern jet stream does.

Ferrel cell
These cells are balanced by the Hadley and polar cells, and create westerly winds. They are sometimes referred to as the 'zone of mixing'.

Northern polar jet
Travelling west to east around the northern hemisphere, it helps keep northern Europe temperate.

Polar cell
These north-south circulating winds bring in cold air from the freezing poles and produce polar easterlies.

Hadley cell
This atmospheric cell is partly responsible for the deserts and rainstorms in the tropics.

Subtropical jet
These winds are much higher in the atmosphere than their polar counterparts, at around 17,000m (55,000ft).

Southern polar jet
The southern hemisphere's jet stream runs around the circumference of the Antarctic landmass.

Winds of change

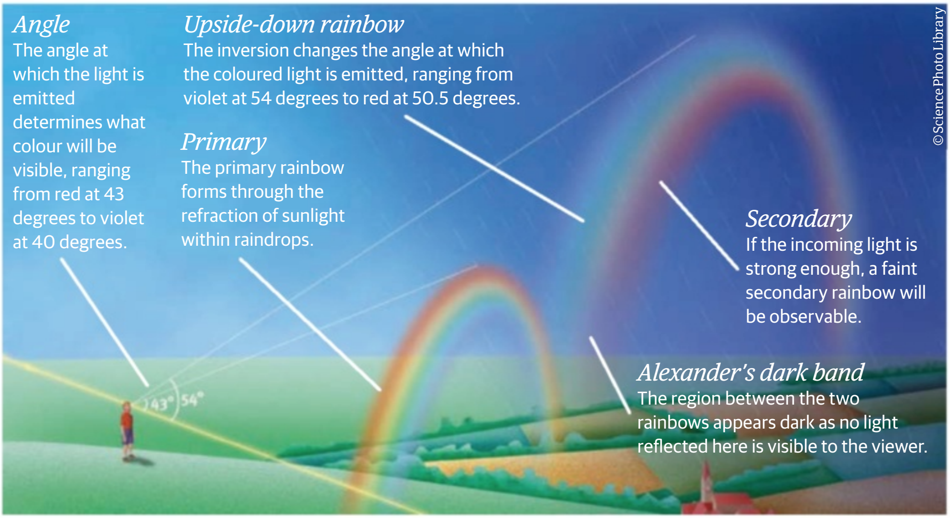
Currents in the jet stream travel at various speeds, but the wind is at its greatest velocity at the centre, where jet streaks can reach speeds as fast as 322 kilometres (200 miles) per hour. Pilots are trained to work with these persistent winds when flying at jet stream altitude, but wind shear is a dangerous phenomenon that they must be ever vigilant of. This is a sudden, violent change in wind direction and speed that can happen in and around the jet stream, affecting even winds at ground level. A sudden gust like this can cause a plane that's taking off/landing to crash, which is why wind shear warning systems are equipped as standard on all commercial airliners.

What causes double rainbows?

How these colourful meteorological phenomenons are caused

Regular rainbows occur when moisture in the air refracts sunlight in such a way that it is broken up into its constituent colours. The phenomenon occurs when the Sun is positioned behind you and sunlight passes through the airborne water. The light refracts (bends) inside the droplets and the white light is broken up. Each colour has a different wavelength so, depending on the angle of refraction, a different colour of light will be reflected outwards; the result of this process is what we observe when we see a rainbow.

Every rainbow is accompanied by another, secondary rainbow, but it's usually too dim to see. This double rainbow effect is due to the continued reflection of light inside each water drop. Sunlight is actually reflected twice inside a drop: once to produce the primary rainbow and a second time at the back of the drop. This second reflection inverts the light but undergoes the same refraction, so exits in the same way as before – though upside down. This second reflection reduces the intensity of the sunlight, but it also produces a second inverted rainbow, creating a double arc of multicoloured light.



Which animal has the best sight?

What can see further than anything else?

Birds of prey boast the greatest visual acuity of all animals and zoologists believe some hawks and eagles have vision eight times sharper than ours. An eagle's retina sports around 1 million sensory cells per square millimetre – around five times what you'd find in a human retina. It pays off: some birds of prey can spot and track a rabbit 1.5km (0.9 miles) away!

If you gauge eyesight in terms of light spectrum perception instead of acuity, the mantis shrimp is the champ. Mantis shrimp perceive 11 or 12 primary colours, putting our three to shame, and they see ultraviolet and infrared light too.

Below
Some eagles have vision eight times sharper than ours

© Richard Bartz

Why does water turn white?

Discover which part of a river's course provides the setting for some of the world's most dangerously turbulent water

White water occurs in the upper course of a river when the gradient and obstacles disturb the flow of water, causing it to churn and create bubbles. These bubbles reflect back much of the light that hits them, making the water appear white. Whether a river flows smoothly often depends on its speed, and the steeper the riverbed, the faster the water will flow.

The combination of fast-flowing water and obstacles like rocks causes the flow to become turbulent, with unpredictable variation in the speed and direction of the water. This creates a variety of features in the river. Where water doubles back on itself, pockets filled with bubbles open up; these provide much less buoyancy and feel like 'holes'. Objects lodged in the river can act as strainers, allowing water to pass through, but blocking larger debris. In areas where the water moves rapidly, it wears away at the surface of rocks underneath, creating undercuts.

The challenges of navigating the features of white-water rapids - whether jutting rocks or whirlpools - attract kayakers and rafters every year.

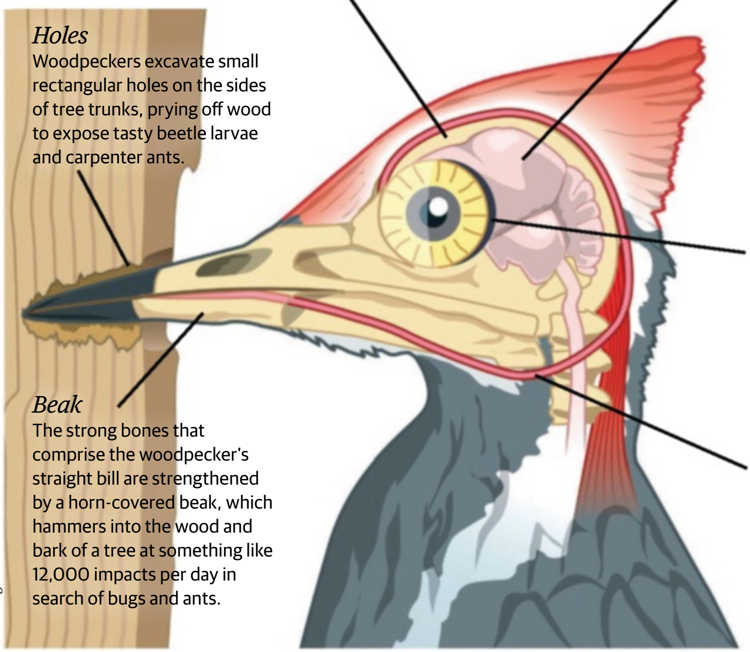
Why don't woodpeckers get headaches?

How a thick skull keeps it injury free

Woodpeckers whack their heads against wood up to 20 times a second, at 1,200 times the force of gravity, without suffering concussion, detached retinas or any other symptoms of head injury. This is achieved through the incredible structure of their heads.

Skull
Woodpeckers have a thicker skull than most other birds. It's made of extremely strong yet spongy compressible bone, to help cushion the blow. The beak and skull are linked by elastic connective tissue.

Brain
Unlike human brains, which are floating about in a pool of cushioning cerebrospinal fluid, woodpecker brains are tightly enclosed in the skull with practically no cerebrospinal fluid.



Holes
Woodpeckers excavate small rectangular holes on the sides of tree trunks, prying off wood to expose tasty beetle larvae and carpenter ants.

Beak
The strong bones that comprise the woodpecker's straight bill are strengthened by a horn-covered beak, which hammers into the wood and bark of a tree at something like 12,000 impacts per day in search of bugs and ants.

Third eyelid
Woodpeckers have a thick inner eyelid, which acts as a seat belt to ensure the bird's eyeballs don't pop out and also prevents tearing the retina. The eye is filled with blood to support the retina.

Hyoid apparatus
Within the long tongue is a skeletal structure called the 'hyoid apparatus'. This is a collection of small bones supported by cartilage and muscles, which fold up like an accordion and enable the woodpecker to stick its tongue out further.

How do Venus flytraps work?

Discover how these plants lure their prey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Venus flytraps, like the rat-eating carnivorous plant, tend to grow in boggy soil that's low in nutrients, hence they need to find another source of food to sustain them, namely insects that happen to land on their leaves. These leaves are about eight to 15cm long and are 'hinged' along the midline with spiny teeth around the edges. The folding and trapping action is triggered by pressure on six sensitive hairs that, when stimulated will snap the leaf shut in about half a second, although the actual nature of the action is still debated. As well as these sensitive hairs, the leaf also has glands on its surface that secrete a sap which digests the insect's body. This process takes about ten days, after which the leaf reopens.

Does China own all pandas?

Are the world's pandas all owned by the global superpower?

Not quite. In the wild, giant pandas only live in China but captive ones have been sent to zoos around the world as gifts since the Fifties. None of those pandas are still alive though and, since 1984, almost all pandas have been given to zoos on a ten-year lease. They remain Chinese property and so do any cubs born in captivity from the leased pandas. There are a few exceptions, however. In 2008 China gave, rather than leased, a pair of pandas to Taiwan and in August 2013 they were successfully bred to produce a third Taiwanese panda, called Yuan Zai.


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Right
Pandas can be found in zoos around the world, often on lease from China

Which is the world's tallest waterfall?

There are two contenders for the title of world's tallest waterfall. Angel Falls is found in Venezuela and Tugela Falls in South Africa, but which one claims the title depends on the criteria. The debate is whether to award the title to the tallest single drop or to the tallest sequence of falls. Angel Falls easily wins the tallest drop contest with a breathtaking 807-metre (2,648-foot) cascade. But Tugela Falls is a series of five falls in quick succession, whichtaken together drop a total 948 metres (3,110 feet). When Angel Falls was originally measured in 1949, the American expedition included a second 30-metre (98-foot) plunge farther downstream. If you include the sloping rapids between these two falls, the total drop in elevation is 979 metres (3,212 feet).

Angel Falls was named after aviator Jimmie Angel who spotted it from the air while searching for gold in the region

What is fracking?

Hydraulic fracturing enables us to tap into shale gas reserves trapped deep underground, but what does this mining process entail?

As we exhaust more easily accessible natural gas reserves, countries across the globe are increasingly turning to shale gas. But how do you release gas that's imprisoned in millions of tiny pores inside shale rock, deep beneath Earth's surface? The answer is hydraulic fracturing, or fracking.

Fracking involves drilling deep into rock and pumping a highly pressured jet of water, sand and chemicals down the wellbore. This forces a network of tiny cracks to open up and spread through the impermeable rock, allowing pockets of gas within the rock to seep out.

The main ingredient that makes up fracking fluid is water. Since water is incompressible, it can pass on the extreme pressures needed from the pump to the shale rock over 2,000 metres (6,560 feet) below. Sand or ceramic beads act as 'proppants', holding the cracks open after the pressure drops and while the gas is collected.

Finally, a cocktail of different chemicals is added. Their uses range from averting micro-organism growth to preventing corrosion of metal pipes, maintaining fluid viscosity and reducing friction during extraction.

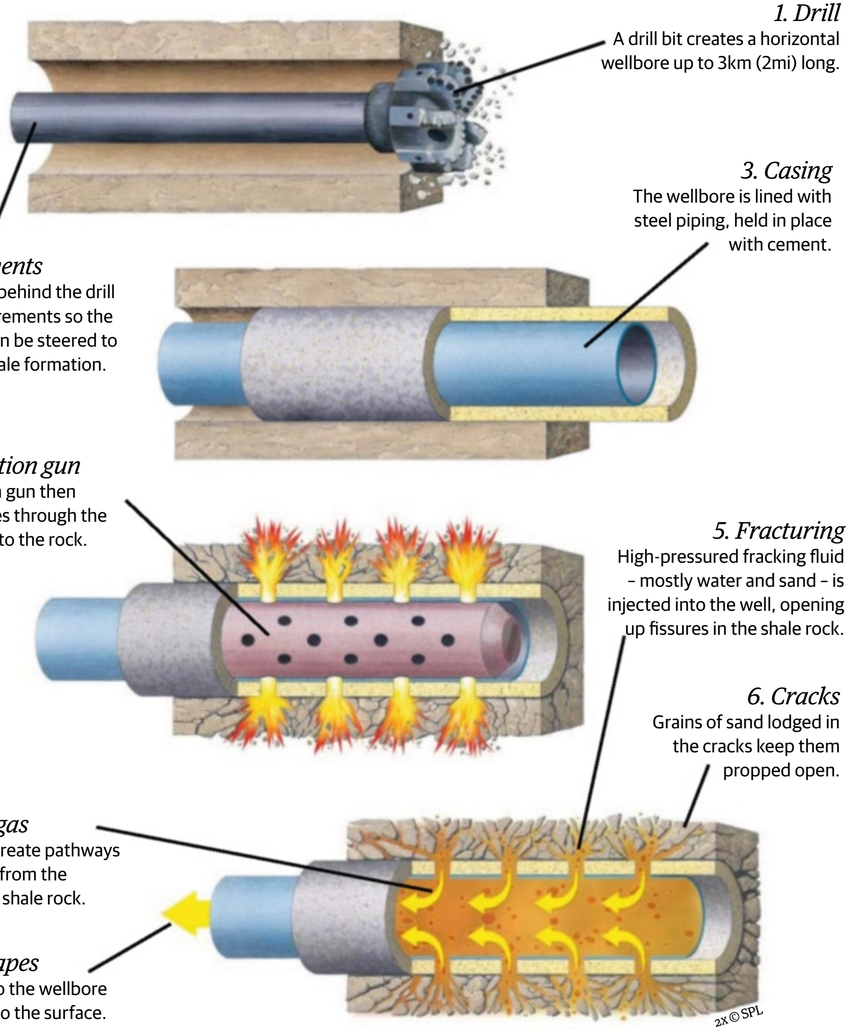
Hydraulic fracturing was first used in the 1940s, but is far more efficient today. The advent of horizontal drilling in the Nineties, for instance, made wells far more productive, making the operation economically viable.

While fracking has allowed governments to unlock previously unreachable and abundant shale gas resources, it has sparked concerns among some geologists and conservationists. A fracking well uses millions of litres of water per


© Thinkstock

Below
Water contamination is one of the worries associated with fracking

frack, putting pressure on local water resources. Around half of the fracking fluid remains in the rock and, although much deeper than groundwater, some fear it could, over time, contaminate drinking supplies. The fluid recovered at the surface also needs to be disposed of safely. Finally, geologists must ensure fracking sites are far away from fault lines since they can increase the likelihood of earthquakes and tremors in at-risk areas.



How safe are roller coasters?

They strike fear into many, but we still love them! Here, we detail the engineering achievement that is the roller coaster

Believe it or not, some of the world's most forward-looking engineering is actually in operation right now, in the unexpected setting of the world's theme parks.

From the pioneering 18th Century 'Russian Mountains', people have been hooked on the frightful thrill of a roller coaster – and ever since, the challenge has been to make an even bigger, even better, even more terrifying one.

Today, they incorporate solutions that are at the leading edge of scientific development. This means they are able to accelerate as fast as a drag racer and let passengers experience G-forces way in excess of a Formula 1 race car.

They do all this in complete safety, having passed the very strictest engineering standards. People travel for miles to ride on the latest roller coaster – they'll even cross continents just to experience the thrill.

Roller coaster trains are unpowered. They rely on an initial application of acceleration force, then combine stored potential energy and gravitational forces to continue along the track. This is why they rise and fall as they twist and turn.

There are various methods of launching a roller coaster. Traditionally, a lift hill is used – the train is pulled up a steep section of track. It is released at the top, where gravity transfers potential energy into kinetic energy, accelerating the train. Launches can be via a chain lift that locks onto the underneath of the train, or a motorised drive

tyre system, or a simple cable lift. There is also the catapult launch lift: the train is accelerated very fast by an engine or a dropped weight.

Newer roller coasters use motors for launching. These generate intense acceleration on a flat section of track. Linear induction motors use electromagnetic force to pull the train along the track. They are very controllable with modern electronics. Some rides now have induction motors at points along the track, negating the need to store all the energy at the lift hill - giving designers more opportunities to create new sensations. Hydraulic launch systems are also starting to become more popular.

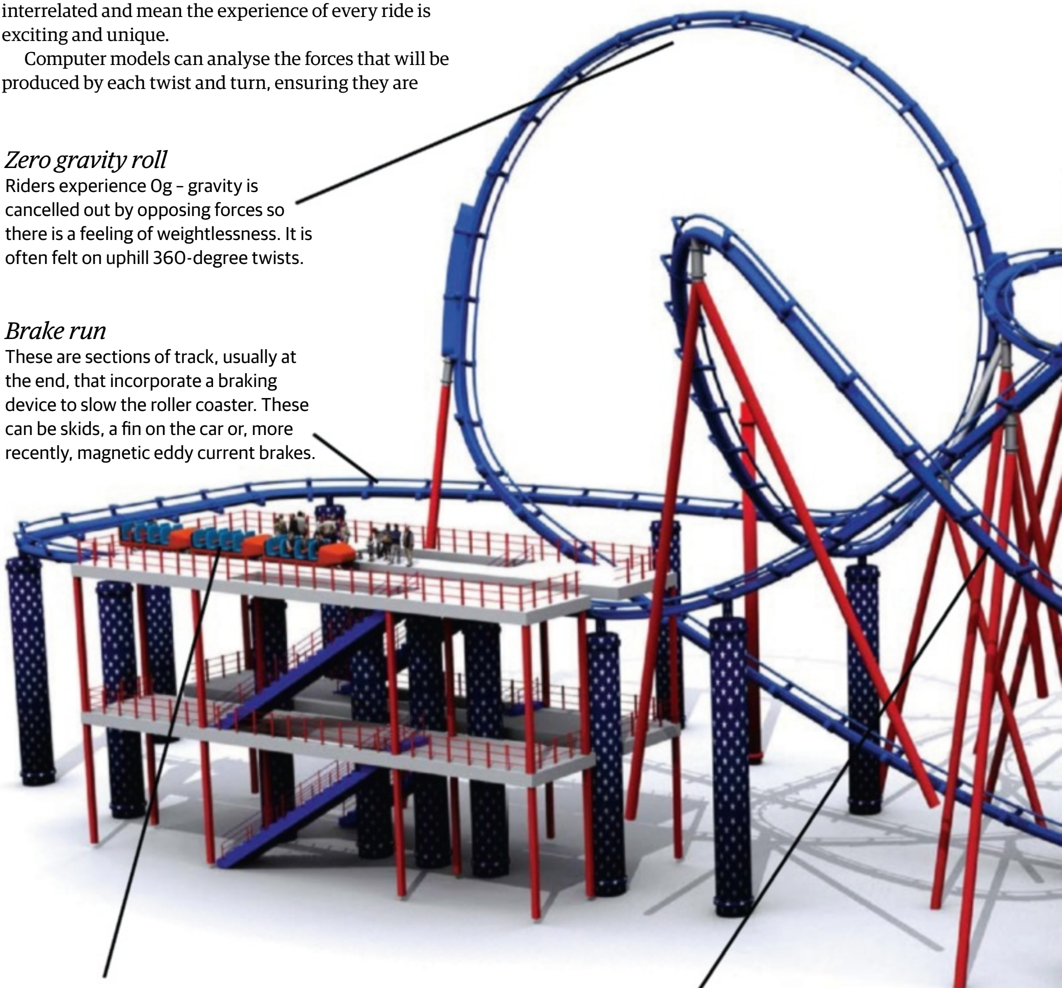
Careful calculation means a roller coaster releases roughly enough energy to complete the course. At the end, a brake run halts the train - this compensates for different velocities caused by varying forces due to changing passenger loads.

Below
The Stealth ride at Thorpe Park isn't for the faint-hearted

How are roller coasters designed?

Roller coasters comprise many elements, each with its own specific physical characteristics. Designers give a ride character by applying an understanding of physics to build up a sequence of thrills. These are all interrelated and mean the experience of every ride is exciting and unique.

Computer models can analyse the forces that will be produced by each twist and turn, ensuring they are kept within specific boundaries. Roller coasters may look like just a random snake of track, but the reality is actually years of scientific calculations to provide just the right effects.



Zero gravity roll
Riders experience 0g – gravity is cancelled out by opposing forces so there is a feeling of weightlessness. It is often felt on uphill 360-degree twists.

Brake run
These are sections of track, usually at the end, that incorporate a braking device to slow the roller coaster. These can be skids, a fin on the car or, more recently, magnetic eddy current brakes.

Train
Two or more cars linked up are called a train. The position of the car in a train dictates the effects on the riders.

Dive loop
A dive loop is a type of roller coaster inversion where the track twists upwards and to the side, and then dives toward the ground in a half-vertical loop.

Corkscrew

Among the most famous roller coaster elements – trains enter the corkscrew and are twisted through 360 degrees to emerge travelling in a different direction.

Lift hill

The lift hill is the first rising section of track containing the drive mechanism to raise the roller coaster to the summit.

Headchopper

Designers build the layout tightly so they 'appear' to risk chopping passengers' heads off as they approach! The reality is there's ample clearance, but it's a big part of the thrill.

© Alex Pang

Can phones work underwater?

What's needed to make these valuable devices waterproof?

Today there are two main methods for waterproofing a smartphone: physical barriers such as port covers and sealed seams that prevent liquid entering externally, and nanocoatings that penetrate the device entirely and actively repel water. While both techniques are used, the most effective is the latter, enabling devices to be water resistant without compromising on size and aesthetics. There are different types of nanocoating, but one of the most commonly used is that made by P2i. This company's waterproofing process involves subjecting any electronic gizmo to a plasma-enhanced vapour in a vacuum chamber at room temperature. The vapour contains a gaseous polymer, which when brought into contact with the device's surfaces – both external and internal – forms a super-strong covalent bond and waterproof barrier 1,000 times thinner than a human hair.

Once on the phone, the ultra-thin polymer layer then dramatically reduces its surface energy, forcing any water that comes into contact with it to bead up and be repelled. Obviously, in the case of a smartphone, this action would prevent water from penetrating the delicate internal components. However, due to the vapour disposition process, even if water were to penetrate the mobile's casing, each internal component would also be coated with the polymer, protecting them until the water evaporated or was dried off manually.

© Sony

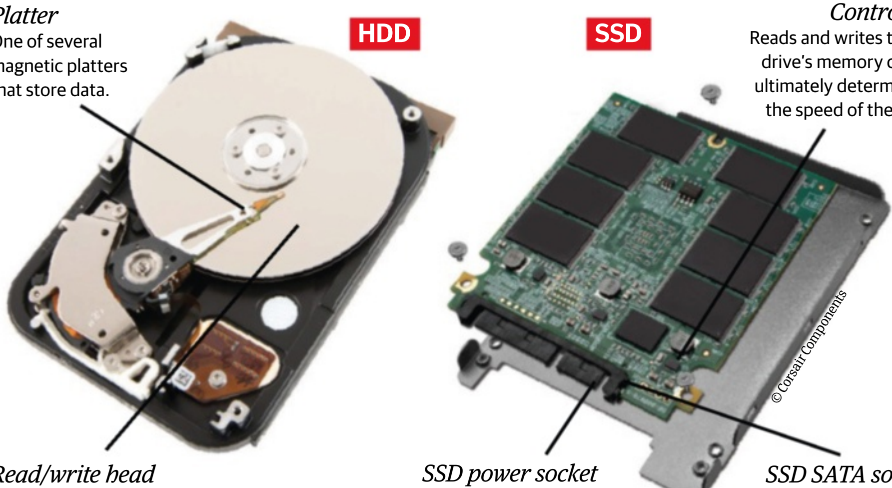
Right
As the Z Ultra is IP55/IP58 certified, it can be submerged in up to 1.5m (4.9ft) of freshwater without risk of damage. It is also protected from low-powered jets of water.

What's inside a hard drive?

Why are solid-state drives superseding hard-disk drives?

Hard-disk drives (HDDs) have been around since IBM conceived of the need for extra computer storage in 1956. A hard disk uses magnetised platters made of aluminium, ceramics or even glass to store data. These are typically rotated at 5,400 or 7,200 revolutions per minute for drives in home PCs. An arm that hovers just above the platters reads data from and writes data to the disk. SSDs, meanwhile, are built very much like the USB flash drives that have become popular over the last decade. There are no moving parts in an SSD, which helps it to access data significantly faster. SSDs use a type of memory called NAND, which is non-volatile: instead of writing a magnetic pattern to a ceramic substrate, it stores data as an electrical signal that it retains even after the computer is switched off. Each SSD features a small processor called a controller, which performs the same role as the read/write arm of an HDD.

Below
Take a closer look at the key differences between these electronic storage devices



Platter
One of several magnetic platters that store data.

Read/write head
Hovers just above the surface of each platter performing both read and write operations.

Controller
Reads and writes to the drive's memory chips, ultimately determining the speed of the SSD.

SSD power socket
A standardised socket that plugs directly into the computer power supply.

SSD SATA socket
Standardised data transfer – no different to that used by modern-day HDDs.

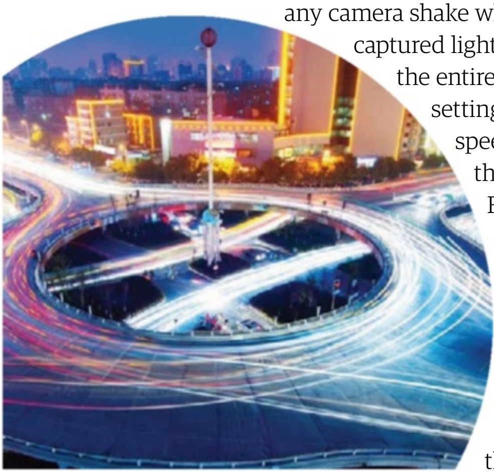
How are light trails captured?

How are these bright, abstract streaks of light caught on camera?

Light trails are a colourful and creative effect that photographers can capture by employing long-exposure shooting on their camera. The basic principle of light trail creation is that by manually dropping a camera's shutter speed to a very low level, light is captured by the sensor over an artificially long period of time, with every passing vehicle having its lights tracked and recorded over the visible distance of the road.

To take a shot like this one, find a roadside vantage point in which no other moving objects are visible other than the passing vehicles. Second, mount the camera on a tripod, as stability is key while shooting long-exposure imagery. This is because if there is any camera shake while the unit's shutter is open, then the captured light will lose its direction and smudge across the entire image. Next select the shutter priority setting on the DSLR camera and drop the shutter speed to the desired level – for shots like these, this means at least a 30-second exposure. Finally, automatically focus on the scene's background and use an external remote to take the picture. Interestingly, the very same process is also used in light painting, a technique where the streaked light is controlled by the photographer manually, using light-emitting diodes (LEDs) to draw custom streaks across a dark backdrop and thereby essentially 'painting' in light.

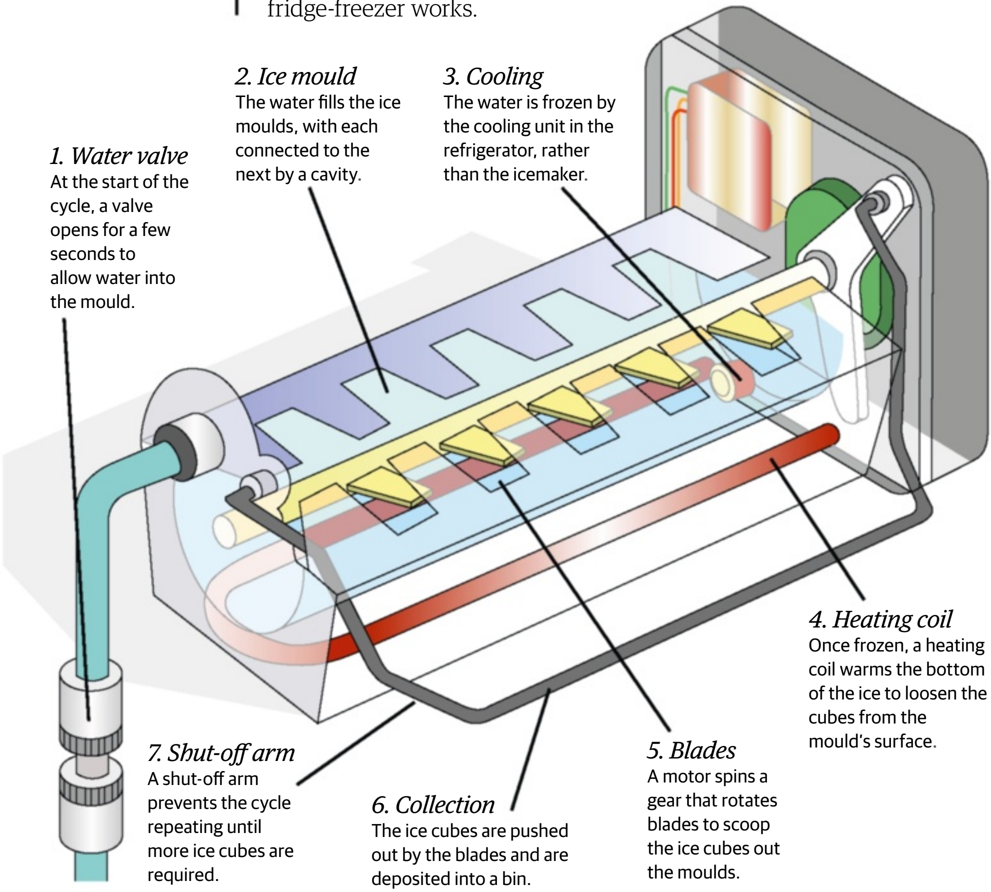
Below
The trails of light here are all the result of passing vehicles. They follow the direction that the vehicles were travelling while the camera was shooting



How do machines make ice?

How do these machines produce ice cubes in bulk to keep our drinks cool?

Icemakers are essentially conveyor belts of ice cubes made for instant use. They come in a variety of shapes and sizes for different purposes, but almost all use the method of freezing water in a mould and then heating it slightly so the ice cubes slide out with ease. Here we look at how a conventional icemaker built into a domestic fridge-freezer works.



Can a compass work underground?

Would a traditional compass work beneath the surface?

The compass app on your phone probably won't work because it relies on radio signals that are easily blocked by rock or water, but for a compass with a wobbly needle, it just depends on how far underground. A compass works because its magnetised needle lines up with the magnetic field that runs between Earth's north and south poles, and that field is just as powerful if you go down a mineshaft or into the depths of the ocean. But the field is created by swirling molten iron in Earth's core, and if you could drill that far down, you'd find your magnetic needle going haywire.

Right
A compass like this might work underground – it just depends how far!

Should print inks be primary colours?

What are the best colour inks to use in printers?

Suppose printers used red, green and blue ink instead. Which colours would you mix to make yellow? You couldn't do it. Mixing red and green light gives yellow because you are adding together photons of different wavelengths.

But with ink, you start with white ambient light and reflect it off the pigment molecules, which absorb some of the photons. So you are subtracting wavelengths, rather than adding them. The printer ink colours of cyan, magenta and yellow are used because they each absorb one of the primary colours – yellow ink absorbs blue light, and reflects red and green, for example.

How do homing missiles always stay on target?

Missile tech has come on leaps and bounds since the unguided V-2 rockets of WWII, but how do these explosive devices navigate today?

Below
A C-130 Hercules launches flares that can be used to draw away homing missiles during a training mission

Modern missiles can be guided to a target, often by their own systems. The most common kind of homing technology detects and locks on to infrared (IR) radiation, such as the heat from a jet exhaust. Modern systems detect two wavelengths: 3-5 micrometres and 8-13 micrometres. The second wavelength isn't absorbed by the atmosphere, so it's much easier to track. This also makes flares – the intense infrared countermeasures that are ejected by a target in order to lure the missile off course – less effective.

Missiles are essentially rockets fitted with an explosive warhead and an infrared detection sensor connected to a flight computer. These sensors are often made of mercury cadmium telluride to pick up the specific infrared wavelengths emitted by the enemy target.

Taking out a missile

Homing tech can be used for defence as well as attack, as this anti-missile system shows…

4. Acquisition
When it gets to a close enough position, the interceptor's own on-board IR systems lock on to the target.

5. Interception
The missile steers itself towards the incoming bomb, exploding when close enough and destroying them both.

© Ian Moores Graphics

3. Interceptor homing missile
The interceptor is launched, initially targeted at the course the hostile weapon was detected on.

2. Radar station
The launch is detected by a radar station and a targeting trajectory is instantly fed to the interceptor.

1. Enemy missile
A ballistic is fired from a hostile state or aircraft many miles away.

However, sometimes missiles need to be fed targeting information constantly from their launcher, while the on-board flight control system steers the weapon. Indeed, on some occasions this means the target will be 'painted' with a laser; that energy signature will then guide the missile. Others still make use of mounted cameras which let an operator direct the missile post-launch and guarantee it's not duped by countermeasures.

How do barcodes work?

What information do these black-and-white codes contain?

Barcodes are a machine-readable way of writing letters and numbers. A laser is shone onto the barcode and the reflected light can be interpreted by the barcode reader. There are many types of barcodes, but the ones most commonly found in supermarkets use a row of lines of different widths. The different widths represent different numbers. In the UK many items are coded with a GTIN – Global Trade Item Number. This allows the manufacturer to print the barcode on the packages. The numbers are unique to that item. The barcode only has a number, but no product information. That is held in a database which the retailer can access at the point of sale. It also means that shops can set their own prices and change them easily.

What is RAM?

The incredibly vital role that this PC part plays

Random access memory (RAM) is a type of physical data storage that can be used to read and write data to so it can be accessed by a computer's CPU (central processing unit). RAM is considerably faster than the hard disk drive memory used to store files and, as such, allows data to be processed more efficiently. Importantly, unlike hard disk memory, RAM is volatile and does not retain info after power is cut to the machine, resetting for future usage. Today, DDR SDRAM – or double data rate synchronous random access memory – is popular as it provides a high bandwidth for fast reading and writing. Apart from use in PCs, today RAM is also present on most smartphones.

How do flare guns work?

A revolutionary device in ceramics

A flare gun works in the same way as any traditional firearm with one key difference: it must ignite its projectile and propel it high into the sky. Generally credited to Edward Very, the first gun that could fire a flare was tested by the American Navy back in 1882. When the trigger of a flare gun is pulled, a chain of events begins. First, the flare's propellant is ignited as the gun's hammer strikes the detonator cap. The signal is then pushed out of the gun's barrel through deflagration, which is a subsonic combustion process where an intense burning of gases in a small space generates pressure.

The short time it takes to ignite the propellant is enough for the flare to also be lit. These objects burn so brightly because they contain magnesium, an element also used in fireworks. Other chemical additives can produce varying colours. In some cases, the flare will also have an in-built parachute (most commonly for military use) that prolongs its fall to Earth and extends the average 40-second period that a flare will typically burn brightly for.

© Orion

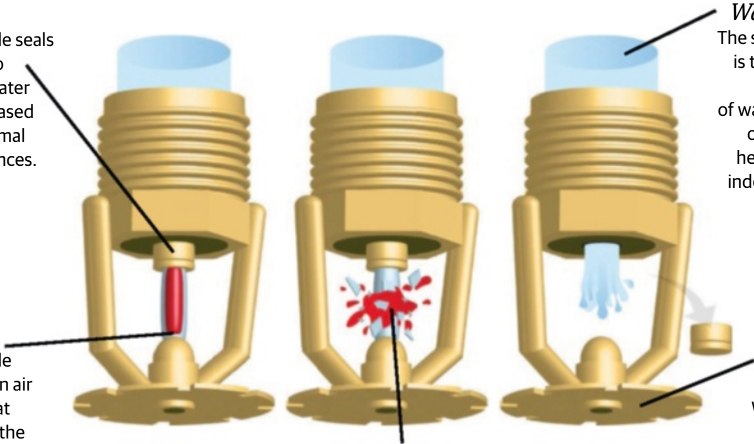
Above
The same mechanism that is used in traditional firearms was only slightly adapted for the flare gun

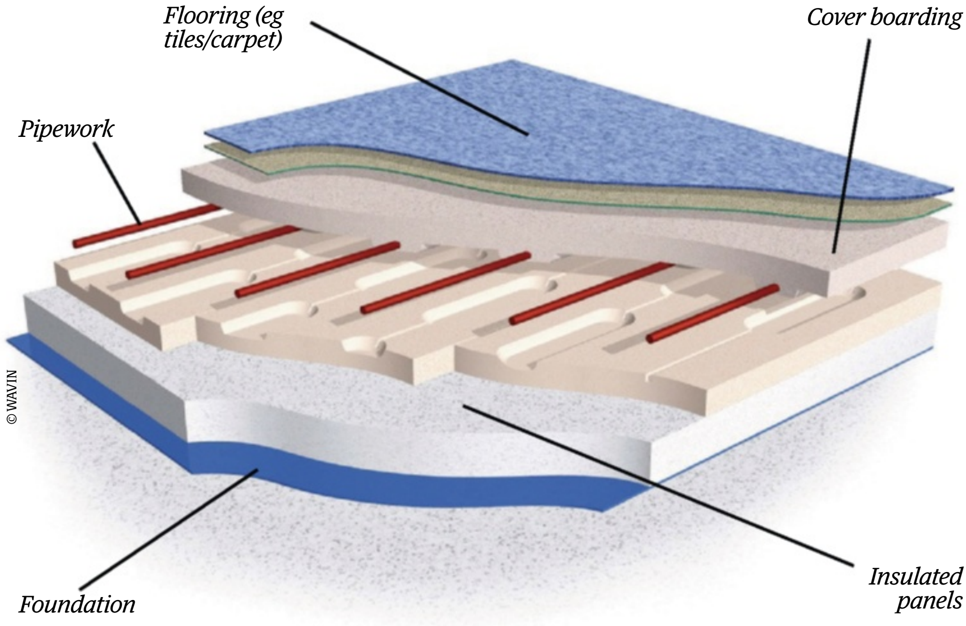
How do fire sprinklers save lives?

A closer look at how these firefighting devices extinguish a blaze

Fire sprinkler systems are fed by pressurised water from the mains or by their own supply. This water is kept from being released by a plug inside the sprinkler head that will only be released when the room's temperature exceeds 68 degrees Celsius (155 degrees Fahrenheit). At this temperature, the tiny ampule that seals the plug mechanism will shatter to release a deluge of water.

In more vulnerable environments, smaller-diameter ampules are used for a faster response time. Some sprinkler heads have spring-loaded plates soldered in place over the plug, and are activated when the solder melts. These are known as closed-type sprinklers, because once they are opened, they will spray water until their supply is cut. The on-off sprinkler features a heat-sensitive pilot valve that stops the discharge of water once the temperature has dropped.





What is underfloor heating?

What is this economical and efficient way of keeping our homes toasty?

Traditional wall-mounted radiator heating systems that are found in most homes convect heat into the room, sending heat towards the ceiling in a circular cycle. In contrast, underfloor heating consists of electric elements, or water pipes, that radiate heat up evenly throughout the whole room. For optimum efficiency, a thermostat in each room can monitor and control the temperature.

Underfloor heating is also unobtrusive and easier to maintain as the elements, or pipework, can be embedded in concrete floors when houses are constructed, or they can be fitted under existing flooring. A saving of 20 per cent can be made on fuel bills, and for buildings with high ceilings, savings can reach as high as 40 per cent compared with traditional heating systems.

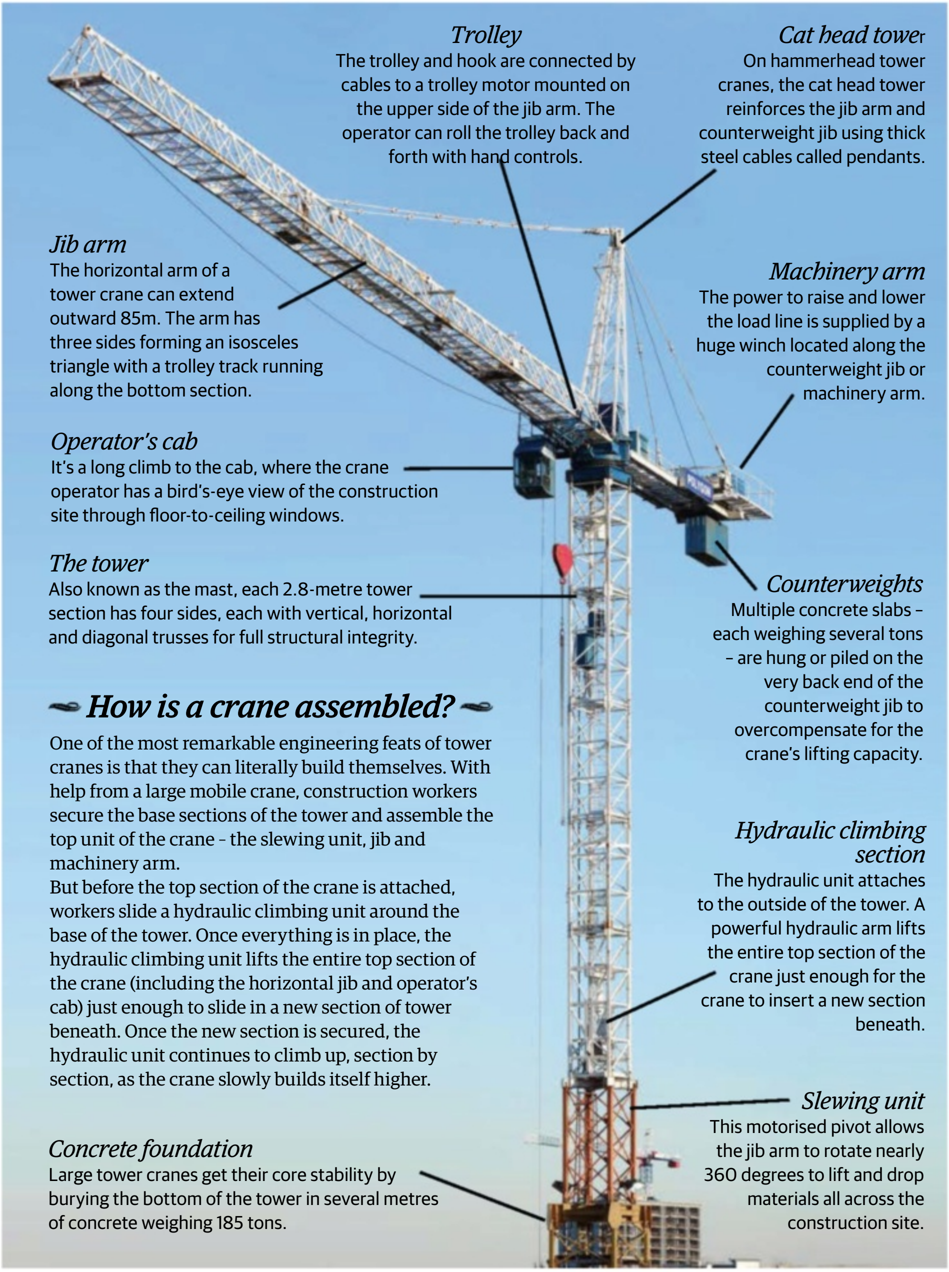
How do cranes get so high?

A closer look at how these magnificent engineering marvels work, and how each individual component is vital

Tower cranes flock to money. During the economic boom years, high-rise construction cranes migrated from Beijing to Shanghai to Dubai, where it was estimated in 2006 that there was one tower crane for every 44 residents of the desert boom-opolis. Tower cranes are feats of structural engineering that often outshine their creations. They are designed to stand 80 metres tall and reach 80 metres out supported only by a narrow steel-frame mast, a concrete foundation and several counterweights.

The engineering principle that keeps the twiggy tower crane from tipping over is something called a 'moment'. If you hang a weight from the crane's jib arm, it exerts a rotational force or torque where the arm connects to the top of the mast. The magnitude and direction of this force (clockwise or anti-clockwise) is called the moment. If the weight is hung close to the mast, the magnitude of the moment is lower than if the weight is hung far out on the jib. To keep the crane upright, counterweights are used to create a moment of equal magnitude in the opposite direction, balancing out the rotational forces.

Once a tower crane meets its maximum unsupported height, it can be tethered to the building itself and continue to grow with the rising skyscraper. The tower cranes that rose with the construction of the record-breaking Burj Khalifa skyscraper in Dubai reached a truly dizzying height of 750 metres.



Trolley
The trolley and hook are connected by cables to a trolley motor mounted on the upper side of the jib arm. The operator can roll the trolley back and forth with hand controls.

Cat head tower
On hammerhead tower cranes, the cat head tower reinforces the jib arm and counterweight jib using thick steel cables called pendants.

Jib arm
The horizontal arm of a tower crane can extend outward 85m. The arm has three sides forming an isosceles triangle with a trolley track running along the bottom section.

Machinery arm
The power to raise and lower the load line is supplied by a huge winch located along the counterweight jib or machinery arm.

Operator's cab
It's a long climb to the cab, where the crane operator has a bird's-eye view of the construction site through floor-to-ceiling windows.

The tower
Also known as the mast, each 2.8-metre tower section has four sides, each with vertical, horizontal and diagonal trusses for full structural integrity.

Counterweights
Multiple concrete slabs – each weighing several tons – are hung or piled on the very back end of the counterweight jib to overcompensate for the crane's lifting capacity.

How is a crane assembled?
One of the most remarkable engineering feats of tower cranes is that they can literally build themselves. With help from a large mobile crane, construction workers secure the base sections of the tower and assemble the top unit of the crane – the slewing unit, jib and machinery arm.

But before the top section of the crane is attached, workers slide a hydraulic climbing unit around the base of the tower. Once everything is in place, the hydraulic climbing unit lifts the entire top section of the crane (including the horizontal jib and operator's cab) just enough to slide in a new section of tower beneath. Once the new section is secured, the hydraulic unit continues to climb up, section by section, as the crane slowly builds itself higher.

Hydraulic climbing section
The hydraulic unit attaches to the outside of the tower. A powerful hydraulic arm lifts the entire top section of the crane just enough for the crane to insert a new section beneath.

Slewing unit
This motorised pivot allows the jib arm to rotate nearly 360 degrees to lift and drop materials all across the construction site.

Concrete foundation
Large tower cranes get their core stability by burying the bottom of the tower in several metres of concrete weighing 185 tons.

What's inside a jukebox?

Combining the traditional look with the convenience and quality of CDs

2x © Sound Leisure

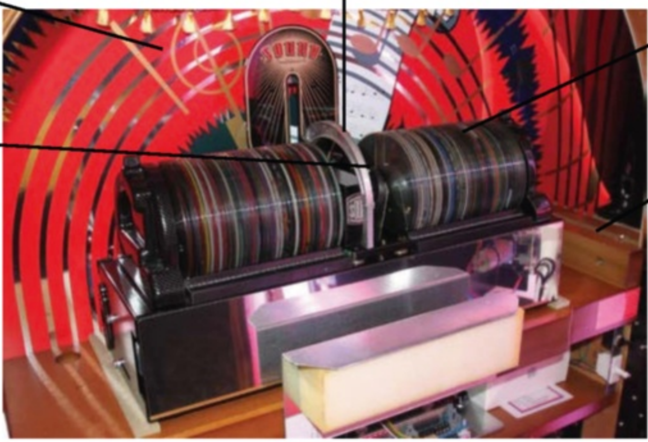
This type of jukebox, with a 21st-Century inner mechanism, holds 80 compact discs (CDs) stacked horizontally on a slotted rack. When switched on, the pick-up mechanism runs on a track to the end of the rack, and then a sensor sends it 40 spaces to the centre of the rack. After a CD or song is selected on the panel of the jukebox, or via a remote-control unit, a location wheel on the pick-up mechanism sends it along its track to the correct CD location.

The pick-up mechanism lifts the selected disc, takes it back to the centre of the jukebox, and drops it down to the playback head. The CD playing head will scan the number of tracks on that disc and play the one that was selected. Once the track has finished the CD is lifted and returned to its original slot and the selection process is ready to start all over again.

Playback
The CD is lowered into the playback mechanism. This clamps the disc in position, scans it and plays the chosen track.

Domed top
The 'bubbler' top is styled after the classic 1946 Model 1015.

CD rack
80 CDs are stacked vertically ready to be selected.



Pick-up mechanism
A notched belt drive sends this along its track to select a CD. A location wheel that sends out a pulse every time it passes each CD slot guides it to the correct position.

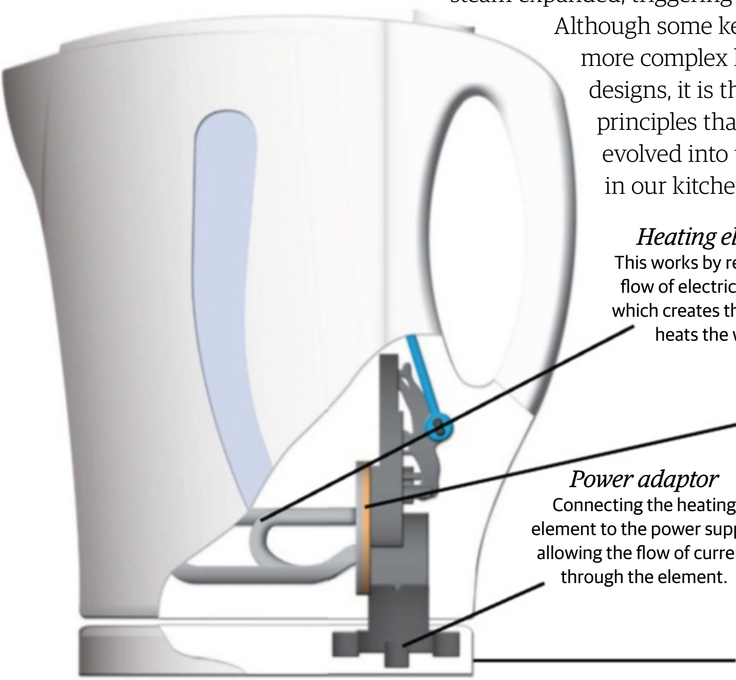
Cabinet
A loudspeaker dominates the space below the top. Decorative tubes contain methylene chloride that is heated to generate a gas that creates a bubble effect.

How do kettles boil water?

Twenties' technology that makes tea-making a piece of cake

The electric kettle works thanks to two design breakthroughs achieved in Britain in the Twenties and Thirties. The first is the immersed heating resistor, the piece of technology responsible for actually heating the water in the kettle. Resistors, which take the form of the heating element in the bottom of the kettle, work by resisting the flow of electric current passed through them, creating resistance and consequently heat. This heat is then passed into the water, which is subsequently heated up. The second of these advances allowed for an automatic cut-off point, preventing the kettle from perpetually heating up the water. A bimetallic strip was introduced to the electric kettle by Russell Hobbs in 1955 which when heated by steam expanded, triggering a shut-off switch.

Although some kettles have fancier and more complex heating and shut-off designs, it is through these two basic principles that the electric kettle evolved into the appliance we have in our kitchens today.



What is gas?

This classic state of matter can be difficult to see but it has some amazing properties

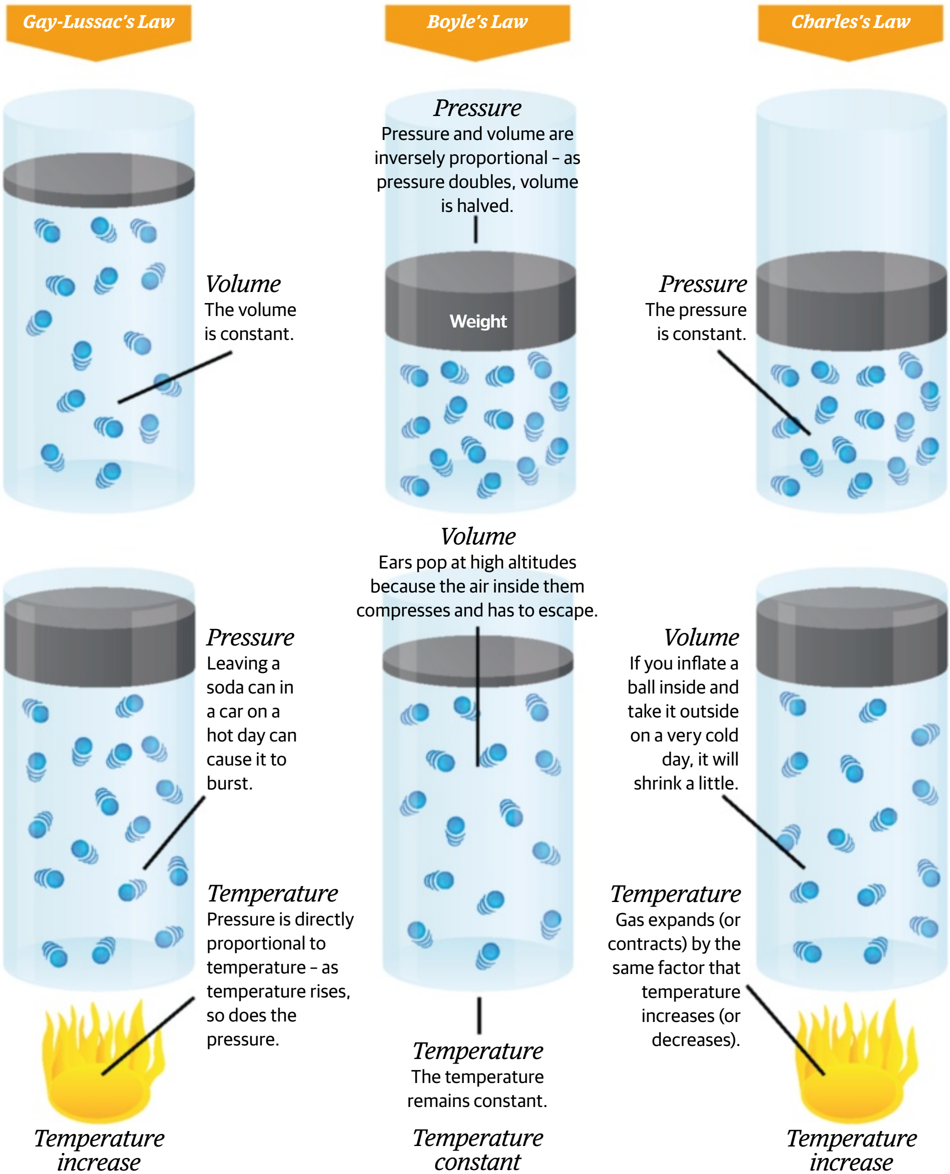
Right
Heated air is less dense than cool air, hence why hot-air balloons rise

Below
Carbon dioxide forces the cork from a champagne bottle

Along with liquids and solids, gases are one of the three major states of matter. Typically they result when a substance is heated in its liquid state to its boiling point, or when evaporation occurs from the surface of a liquid. There are numerous types and classifications of gases, including elements that naturally exist in a gaseous form, compound gases comprising more than one element, and mixtures of individual pure gases.

Gas particles are much more loosely connected than those found in liquid or solid states, which results in lower density – and this is ultimately what sets a gas apart from the other two phases. Without changes in pressure or temperature, gas particles move around freely and randomly. They have no set shape and only change direction and momentum when bouncing off one another or off the inside of a container. Negatively charged areas of particles are attracted to positively charged areas – how these interact varies depending on the gas and are part of what makes each one unique. Because most gases are colourless, they are measured by four different properties: volume, temperature, pressure and number of particles; the latter property is more commonly known as moles. When put into a container (and not pressurised) gas molecules will evenly distribute themselves.

Understanding gases



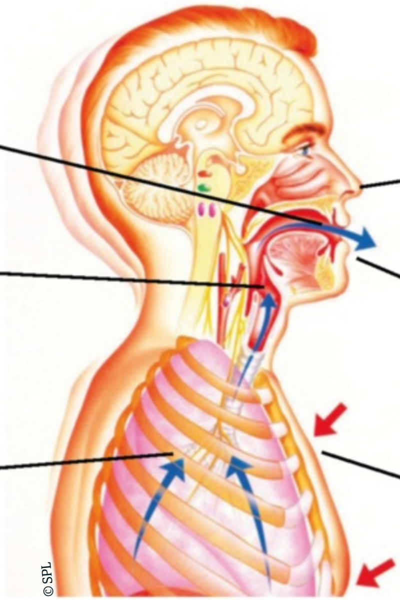
Why do we sneeze?

How does this automatic reflex expel unwanted irritants from the body?

When we breathe in, the inhaled air can contain dust, chemicals and other irritants that can be harmful to the body, particularly to organs in the respiratory system like the lungs. While the tiny hairs inside the nostrils (cilia) trap many of these particles, some will often get through. To help you out, your body reacts to try and forcibly expel the offending particles via the sneeze reflex arc.

There are a number of other reasons why we sneeze, including to clear the nasal passages when you have a cold, to expel allergens if you are allergic to something, and even bright sunlight can cause some people to sneeze.

When a stimuli is detected by the nerve endings in the nose, impulses are sent to the brain, which initiates a chain of physiological events that enable the body to rid itself of the unwelcome item.



1. Irritation
Prior to irritation, the diaphragm muscles are relaxed. When an irritant enters the body, nerve endings in the lining of the nose signal to the brain.

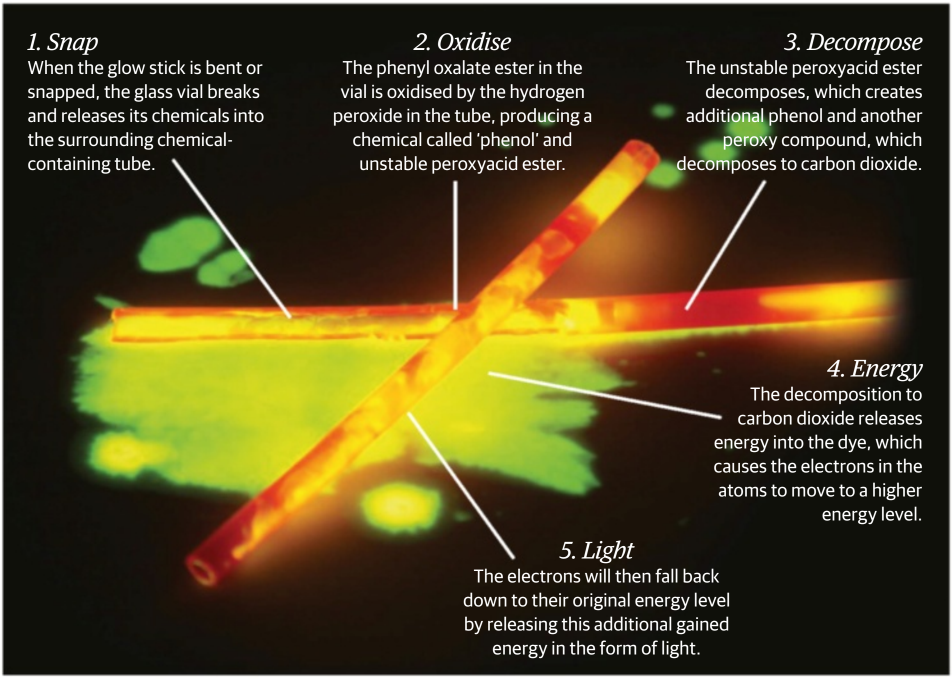
2. Muscles contract
The brain tells the respiratory muscles – including throat, chest and diaphragm – to contract.

3. Intake of breath
Contraction of the diaphragm causes a sharp intake of breath.

4. Air pressure rises
The brain signals to the throat to close. This, combined with the contraction of the abdominal muscles, raises the air pressure inside the lungs.

5. Sneeze
The throat reopens suddenly, explosively forcing air out of the body, making the chest cavity contract sharply. The diaphragm relaxes once again.

6. Mucus
Together with the offending irritant, saliva and mucus from inside the mouth and nasal cavity are also expelled from the body at up to 160km/h (100mph).



How do glow sticks glow?

What's going on inside these popular light sticks?

Inside a glow stick is a thin glass vial containing chemicals. When you bend the stick you're breaking this vial open, releasing the chemicals into the rest of the glow stick, where other chemicals react with them and release light.

Some chemical reactions produce light, known as 'chemiluminescence'. Usually the vial contains a solution phenyl oxalate ester and a fluorescent dye - which will determine the colour of the glow stick - while the surrounding tube contains a solution of hydrogen peroxide. Mixing these compounds causes the electrons to rise to a higher energy level and return to their normal state, releasing energy as light as they do.


©Thinkstock

How does our vision work?

An eye-opening look at how we see...

The eye is often compared to a basic camera, and indeed the very first camera was designed with the concept of the eye in mind. We can reduce the complex process that occurs to process light into vision within the eye to a relatively basic sequence of events. First, light passes through the cornea, which refracts the light so that it enters the eye in the right direction, and aqueous humour, into the main body of the eye through the pupil. The iris contracts to control pupil size and this limits the amount of light that is let through into the eye so that light-sensitive parts of the eye are not damaged.

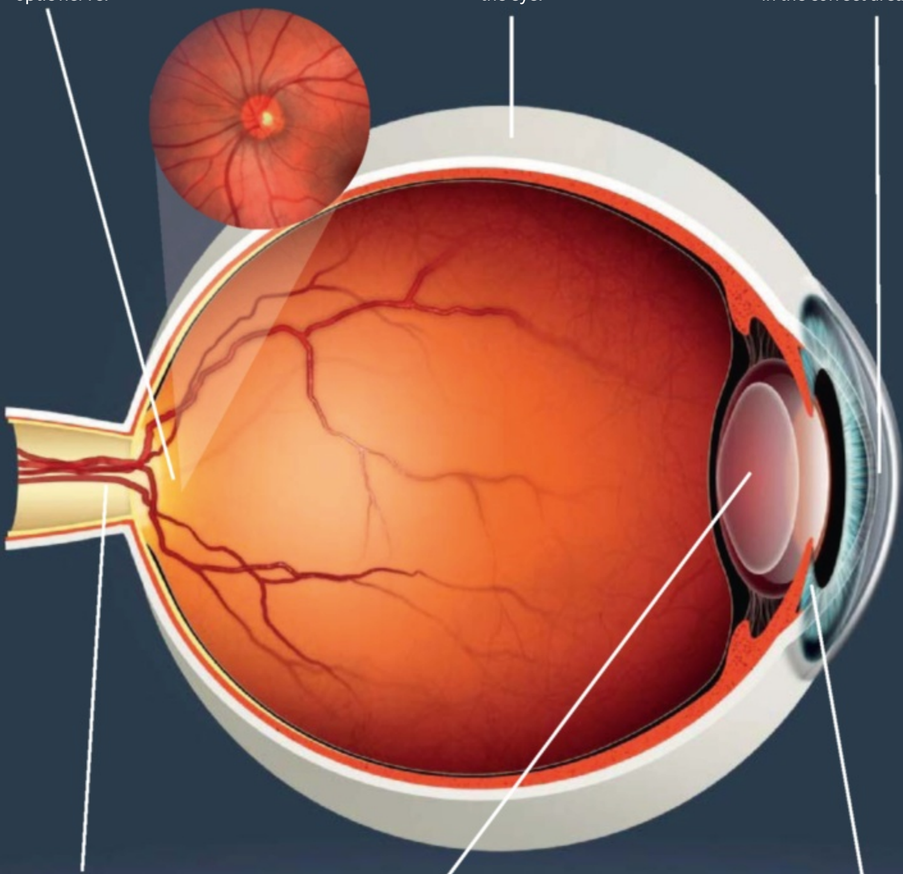
The pupil can vary in size between 2mm and 8mm, increasing to allow up to 30 times more light in than the minimum. The light is then passed through the lens, which further refracts the light, which then travels through the vitreous humour to the back of the eye and is reflected onto the retina, the centre point of which is the macula.

The retina is where the rods and cones are situated, rods being responsible for vision when low levels of light are present and cones being responsible for colour vision and specific detail. All the light information that has been received by the eye is then converted into electrical impulses by a chemical in the retina called rhodopsin, also known as purple visual, and the impulses are then transmitted through the optic nerve to the brain where they are perceived as 'vision'. The eye moves to allow a range of vision of approximately 180 degrees and to do this it has four primary muscles which control the movement of the eyeball. These allow the eye to move up and down and across, while restricting movement so that the eye does not rotate back into the socket.

Retina
The retina is the light-sensitive area which processes light admitted into the eye and converts it into electrical impulses which are transmitted to the brain via the optic nerve.

Sclera
This is the fibrous, white exterior of the eye that is an important protective layer for the more delicate insides of the eye.

Cornea
The cornea is a transparent layer, covering the pupil, iris and aqueous humour. It helps refract the light towards the retina so that light is received in the correct area.



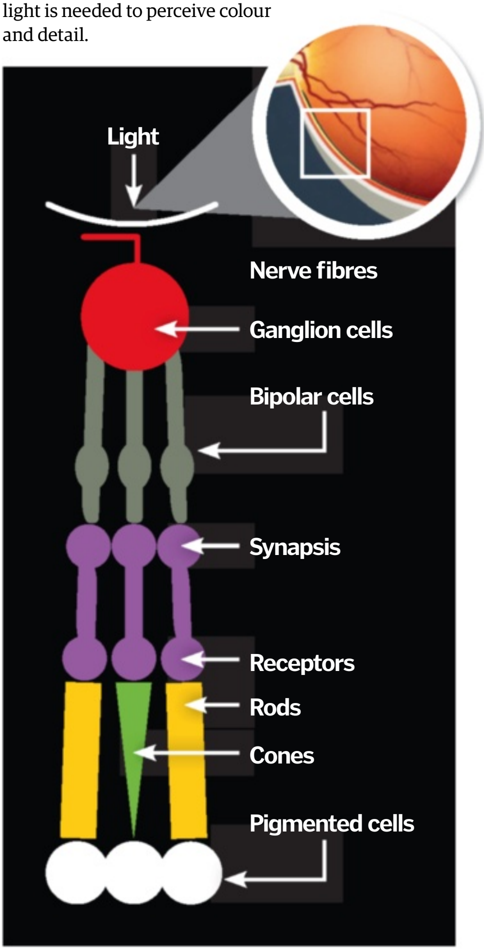
Optic nerve
After the retina has processed light into electrical impulses, the optic nerve transports this information to the brain.

Lens
The lens is a transparent disc in the eye which, with the cornea, refracts light that enters the eye so that it is received by the retina.

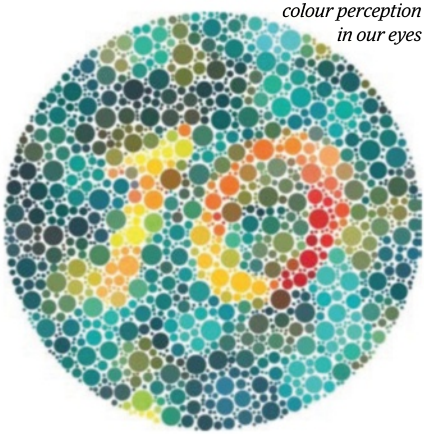
Iris
The iris is the coloured part of the eye which contracts to control the level of light admitted into the eye. The hole which light enters through is called the pupil.

Rods and cones

Rods are the light-sensitive cells in our eyes that aid our vision in low levels of light. Rods are blind to colour and only transmit information mainly in black and white to the brain. They are far more numerous with around 120 million rods present in every human eye compared to around 7 million cones. Cones are responsible for perceiving colour and specific detail. Cones are primarily focused in the fovea, the central area of the macula whereas rods mainly surround the outside of the retina. Cones work much better in daylight as light is needed to perceive colour and detail.



Below
An Ishihara test, which tests for colour perception in our eyes



Seeing colour

Colour is not actually inherent in any object. We only see colour because objects absorb some colour from light, and reflect others. It is the reflected ones that we see and that give an object a set 'colour'. Therefore, for example, grass is not green, it purely absorbs all other colours in light and reflects back green. If an object reflects all colours we will see it as white, if it absorbs all colours we see it as black. We use cones to perceive colour as rods are blind to colour.

How does detergent get our clothes clean?

Discover the chemistry at work inside your washing machine

Anionic surfactants are the workhorse ingredients of most washing detergents. They are compounds such as sodium alkyl sulphate and are made up of molecules that have opposite charges at different points (polar molecules). Water is also made of polar molecules and, when mixed with washing detergent, the hydrophilic (water-loving) part of the surfactant molecule attracts to the water molecule, while the hydrophobic (water-hating) part of the molecule adheres to the dirt and grease in your clothes. This makes the dirt and grime more soluble in the water, allowing for easier removal from your clothing.

Another cleaning effect surfactants have is to lower the surface tension of water. Surface tension is created by these polar molecules pulling on one another due to their charge. This accounts for how pond skaters walk on water and why beads of water hang on grass. By lowering surface tension, the water can become more 'wet' and permeate clothes better.

Grime buster
Surfactants in detergent break down the bonds in water molecules so that they can react better with any molecules of dirt.

Why are bubbles spheres?

The science behind bubbles isn't child's play...

A bubble's skin composed of a thin layer of water molecules sandwiched between soap molecules. Water has a high surface tension due to intermolecular forces. This causes molecules to pull on one another, trying to minimise the surface area and be as flat as possible. Soap reduces this surface tension. However the effect of surface tension is still present which causes the bubble 'film' to be stretched. A sphere is formed because this shape is the shape with the least amount of surface area for its available volume.

Right
Their lifespans are small, but bubbles can provide hours of fun

How does de-icer work?

A common sight during winter, de-icer enables us to drive our cars after cold weather

De-icers work by lowering the freezing point of water, which causes it to turn back from ice into liquid water. Usually this is due to the addition of a chemical compound such as sodium chloride (often called rock salt) or calcium chloride. Most de-icers that you can buy off the shop shelf aren't designed to melt every piece of ice they come into contact with – they simply break the bond between the ice and the surface allowing for easier manual removal of the ice.

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How does whiplash affect us?

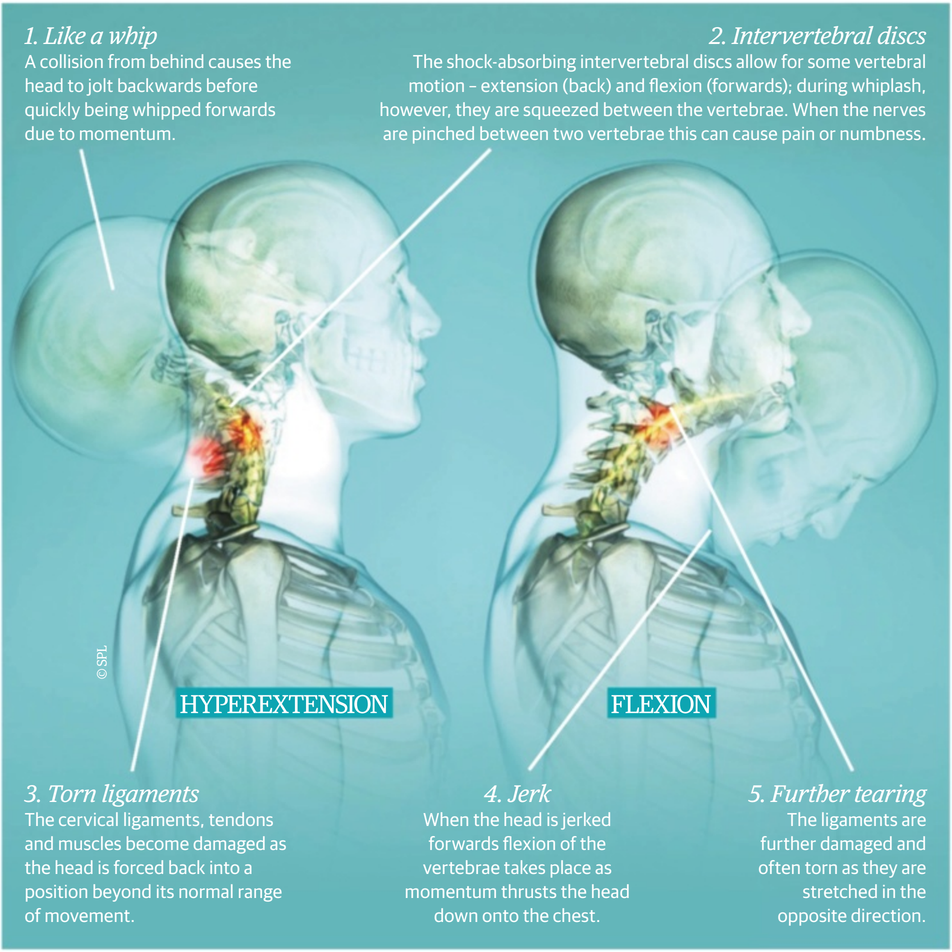
What is this painful injury caused when the neck is forced outside its normal range of motion?

Whiplash is a widespread term used to describe a number of injuries caused when the neck is suddenly and quickly forced to move back and then forth, or forward then back, or even from side to side. Such movement is often the result of a traffic collision, or following a blow to the head or fall during a contact sport.

The bones of the human spine serve to protect the fragile spinal cord which is located within. Of the 33 vertebrae of the human spine, whiplash affects the seven cervical vertebrae found at the top. Vertebrae are connected to one another by bands of fibrous connective tissue called ligaments. They are also connected to the surrounding muscles by tendons. In the event of an incident, damage can be done to both of these tissues in the vicinity of the neck.

During an incident where a vehicle has struck the victim from behind, the head will be forced very quickly back and then forwards, but likewise if the sudden neck movement is due to very abrupt deceleration, the head will instead be jerked in the other direction – ie first forward and then back. Both types can result in whiplash injuries ranging from neck stiffness and loss of movement to back and shoulder pain, headaches and even numbness that can radiate down the shoulders, arms and hands.

It should be noted that although whiplash is considered a fairly minor injury, any head or neck trauma should be checked out by a medical professional. However, most muscle and tissue injuries do not show up on X-rays, so sometimes it can be difficult to diagnose.



Tendons vs ligaments

While both tendons and ligaments are made of collagen cells, that's where the similarity ends. Ligaments are the tough connective tissues that link bone to bone by a joint and provide shock absorbency. They are strong and flexible bands of tissue but cannot be stretched. An overstretched ligament results in a sprain as experienced during whiplash.

Tendons, meanwhile, are the whitish fibrous cords that link one end of a muscle to a bone or other structure. Tendons look white as, unlike muscles, they don't contain many blood vessels.

A damaged ligament can often be surgically reattached to a joint bone, with mobility returning relatively quickly. A tendon, however, is part of the neuromuscular system and so electrical signals must be able to pass across the tendon to reach a muscle in order for it to react. Treatment typically involves a rest period, with a support, and then a gradual return to exercise.

What is centrifugal force?

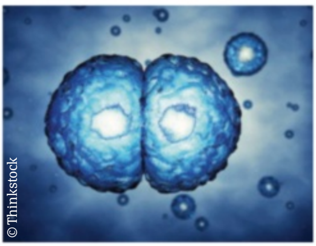
Why do we sometimes feel like being pushed outwards?

Centrifugal force describes the sensation one has of being pushed outward when moving along a circular path. The feeling of being pushed outwards when speeding round a corner in a vehicle, or while riding on a merry-go-round, comes from your preference to move in a straight line. Isaac Newton showed that all objects have inertia and will either stay at rest, or move in a straight line, unless a force acts on them. When you move in a circle there is a force pulling on you, changing your direction from that of a straight line. This is centripetal force and pulls inwards. The feeling of the 'outward pull' of centrifugal force is just your natural resistance to this.

Are cell mutations always bad?

Are they as troublesome as they sound?

A mutation is a change in the genetic material of an organism. We're made from trillions of cells, each with a nucleus composed of DNA – a set of instructions that tells the cell what to do. Cells copy themselves with astonishing accuracy, but every now and then a piece of code is copied incorrectly. This is largely due to natural radiation interacting with our DNA. This incorrect piece of code can become a permanent change in the DNA. Mutations are rarely harmful though. Indeed, most mutations go unnoticed, as the body has mechanisms to stop a cell copying itself. Sometimes mutations can benefit organisms. When a mutation allows an organism to cope better with an environmental stress, it will be passed on to future generations through natural selection.



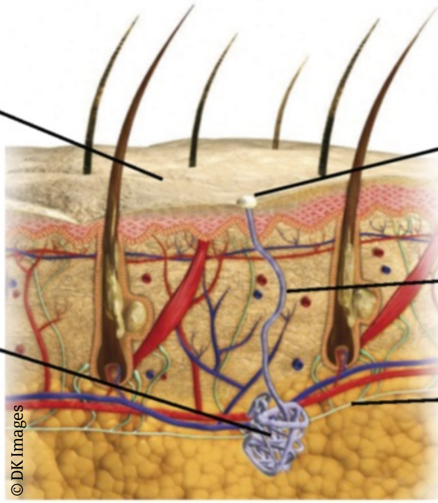
Why do we sweat?

As your doctor may tell you, it's glandular...

Sweat is produced by dedicated sweat glands, and is a mechanism used primarily by the body to reduce its internal temperature. There are two types of sweat gland in the human body, the eccrine gland and the apocrine gland. The former regulates body temperature, and is the primary source of excreted sweat, with the latter only secreting under emotional stresses, rather than those involved with body dehydration.

Eccrine sweat glands are controlled by the sympathetic nervous system and, when the internal temperature of the body rises, secrete a salty, water-based substance to the skin's surface. This liquid then cools the skin and the body through evaporation, storing and then transferring excess heat into the atmosphere.

Both the eccrine and apocrine sweat glands only appear in mammals and, if active over the majority of the animal's body, act as the primary thermoregulatory device. Certain mammals only have eccrine glands in specific areas - such as paws and lips - warranting the need to pant to control their temperature.



What is a vacuum?

Is empty space really empty, and how can we find out?

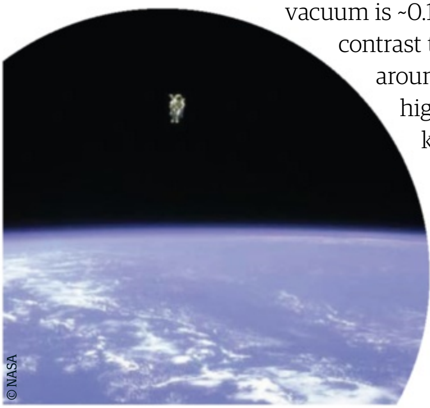
A vacuum is a space that has less gaseous pressure than the standard atmospheric pressure at sea level on Earth. A partial vacuum can be easily created by simply pumping air out of a container. If the container is not sealed, though, the air will be replaced fairly quickly.

In everyday life, vacuums are used in light bulbs, cathode ray tubes, cleaning appliances, and to package, protect and preserve a range of foodstuffs. Creating a vacuum drove the piston mechanism in the Newcomen steam engine and was also used in the braking systems of trains. Household vacuum cleaners work by sucking in air, which creates a lower air pressure than that outside the device. To restore the partial vacuum the outside pressure forces air, and with it dirt/dust etc, into the appliance.

The purest vacuums can be found in outer space. Between galaxies, the vacuum density drops to ~0.001 atoms per cubic centimetre, while in the void between stars in the Milky Way, the vacuum is ~0.1-1 atoms per cubic centimetre. This is in contrast to a vacuum cleaner that produces a vacuum of around 1019 molecules per cubic centimetre, though highly sophisticated extreme-high vacuum (also known as XHV) lab chambers have managed to achieve a vacuum of fewer than 1,000 molecules per cubic centimetre.

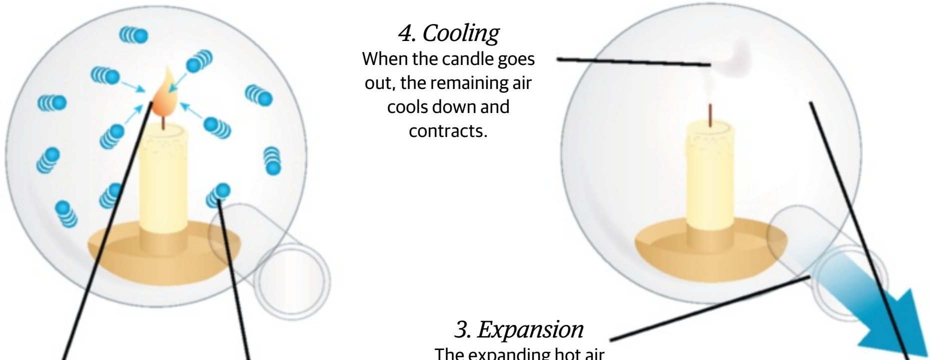
Whether man-made or natural, there is no such thing as a perfect vacuum. Even in a virtually complete vacuum, physicists have discovered the presence of quantum fluctuations and vacuum energy. See opposite for more on fire and sound work inside a vacuum.

Below
Finding something in nothing – the science of the vacuum



Flames inside a vacuum

The lack of air in a vacuum starves a naked flame of oxygen causing it to extinguish



4. Cooling
When the candle goes out, the remaining air cools down and contracts.

3. Expansion
The expanding hot air escapes from the globe.

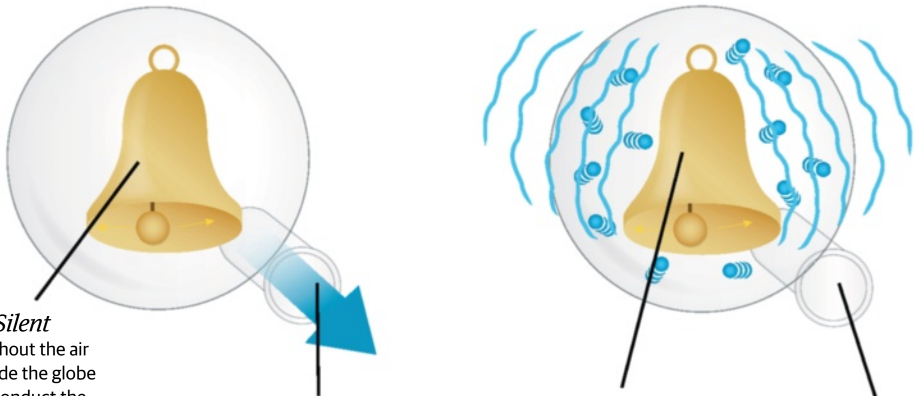
1. Candle
The candle flame consumes the oxygen in the globe.

2. Heat
The heat generated by the flame will cause the air to expand.

5. Vacuum
A partial vacuum will now be created; if the vessel is not sealed the outside air pressure will send air back into the globe.

Sound inside a vacuum

Vacuums induce silence because sound waves require air to travel



3. Silent
Without the air inside the globe to conduct the sound waves from the instrument it can no longer be heard.

4. Seal
If the globe is unsealed to allow the outside air pressure to fill it up again, the sound of the ringing bell will return.

1. Bell
A ringing bell inside the globe can be heard because the sound travels through the air to the outside world.

2. Vacuum
If air is pumped out of the globe, it will create a vacuum.

How do painkillers cure headaches?

The science behind the pills that manage pain

We all feel pain differently, depending on the severity of the injury or ache, as well as our health and our pain threshold. When you are in pain, nerve endings transmit the pain signal to the brain via the spinal cord. The brain then interprets the level of pain.

There are two key types of painkillers that are commonly used. The first include ibuprofen and paracetamol, which block the body's 'prostaglandins' (chemicals that produce swelling and pain) at the source of the pain, reducing swelling in the area and reducing the intensity of pain. These 'aspirin medicines' are used frequently for mild to moderate pain, but they can only work up to a certain intensity of pain. There are different types of painkillers within this group, such as anti-inflammatory medicines, like ibuprofen, which are commonly used to treat arthritis, sprains and strains. Aspirin is used to help lower the risk of blood clots when used in a low dosage, as they thin the blood. Paracetamol is what's known as an analgesic, which is used for reducing pain and lowering a temperature.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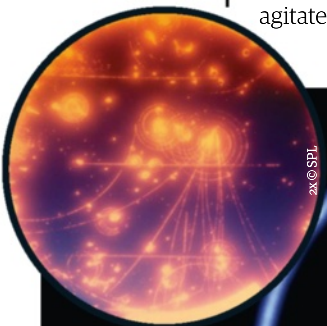
The second type of painkillers include morphine and codeine (narcotic medicines), which block the pain messages in the spinal cord and the brain. This is for much more severe pain. As both types of painkillers use slightly different methods to treat pain, they can be combined, such as in co-codamol, which blends codeine and paracetamol.

What is a photon?

Just how do these tiny packets of light work?

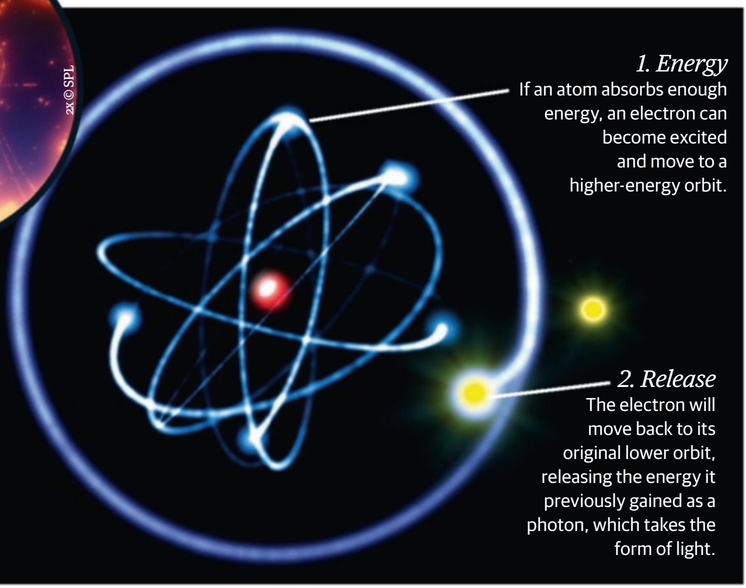
A photon is one of the elementary particles of the universe and is accountable for much of its basic structure. Photons are responsible for one of the fundamental forces of nature - the electromagnetic force - and are often regarded by many as the basic unit of light. They are also responsible for forces in an electromagnetic field and are the main constituent of light that enables it to travel throughout the cosmos.

Photons are basically little packets of energy, or electromagnetic waves, but they contain no mass or electrical charge whatsoever. They are released from atoms when a change in energy occurs, travel at the speed of light and can exist as both a wave and as a particle. When we see light, what we are really observing is the emission of photons from agitated atoms.



2x © SPL

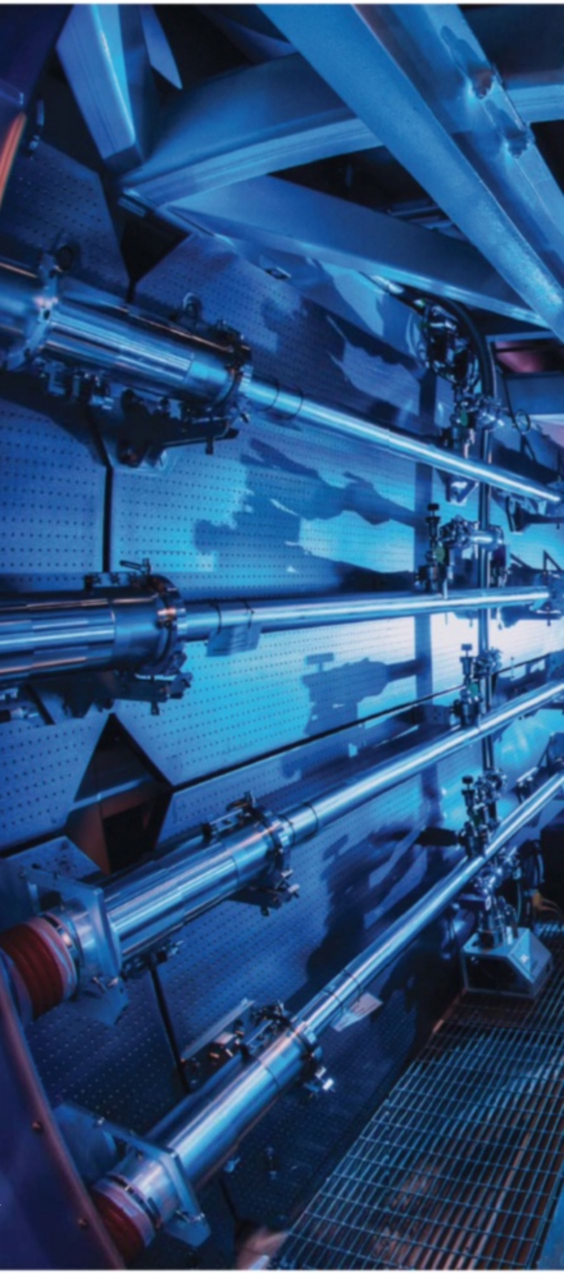
Above
The collision of a hydrogen nucleus (proton) and a high-energy photon



Releasing photons

How big is the world's most powerful laser?

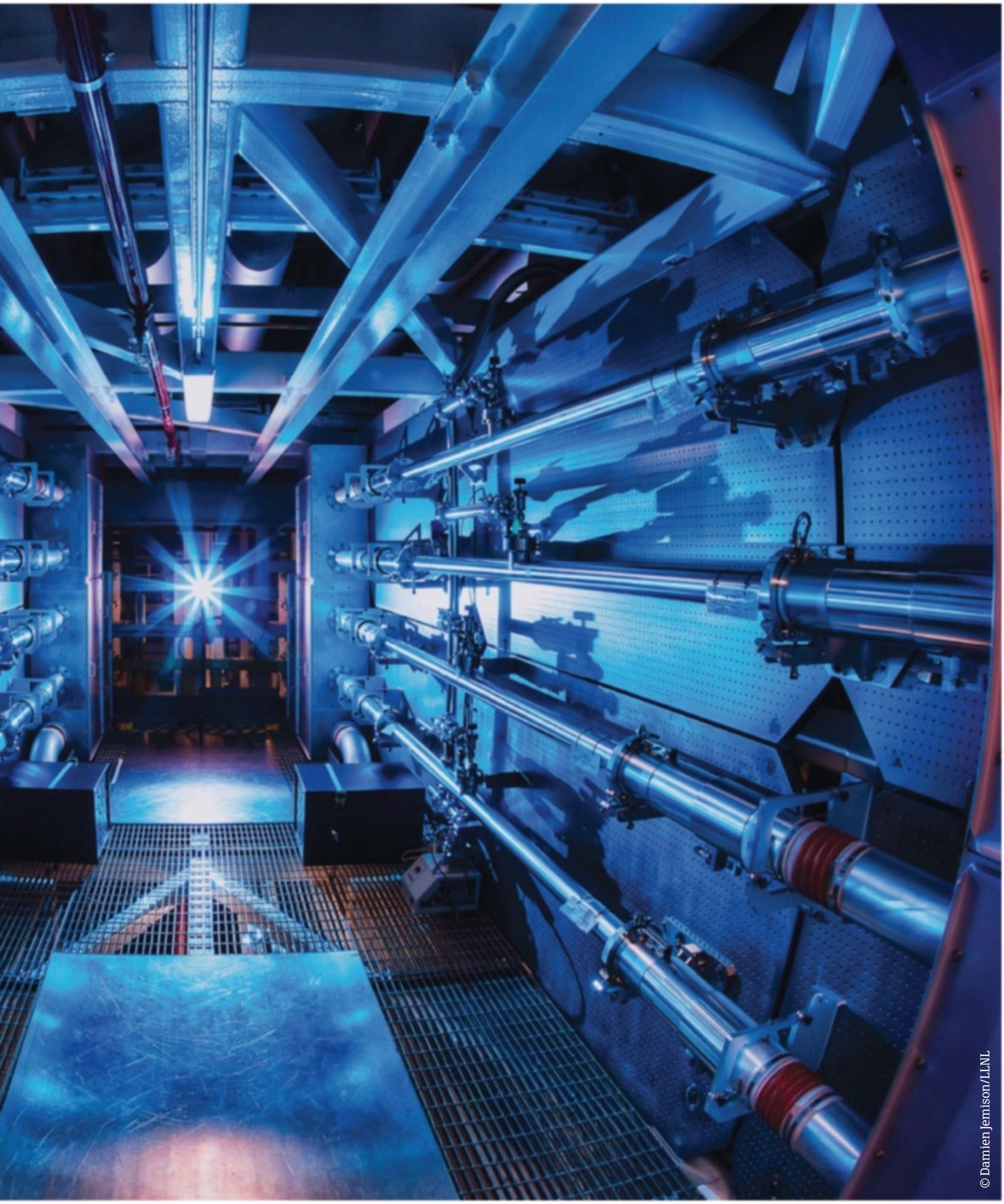
The National Ignition Facility houses the biggest laser, capable of producing around 2 million joules of UV energy



At least 60 times more powerful than its predecessors, the laser at the National Ignition Facility (NIF) in California is an impressive feat of engineering. It contains the largest optical instrument ever built, 7,500 flash-lamps, 97 kilometres (60 miles) of mirrors and fibre optics, and is the size of three football pitches.

At the master oscillator of the NIF, a low-energy pulse of photons is generated using an optical fibre laser. To amplify the laser pulse it is broken down into 192 separate beams; these are then carried through fibre-optic cables to a series of amplifiers.

The combined power of all 192 beams heats the target to 100 million degrees Celsius (180 million degrees Fahrenheit) – more than six times hotter than the core of the Sun – and puts it under a force exceeding 100 billion atmospheres, all in less than a second.



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Why do our muscles ache?

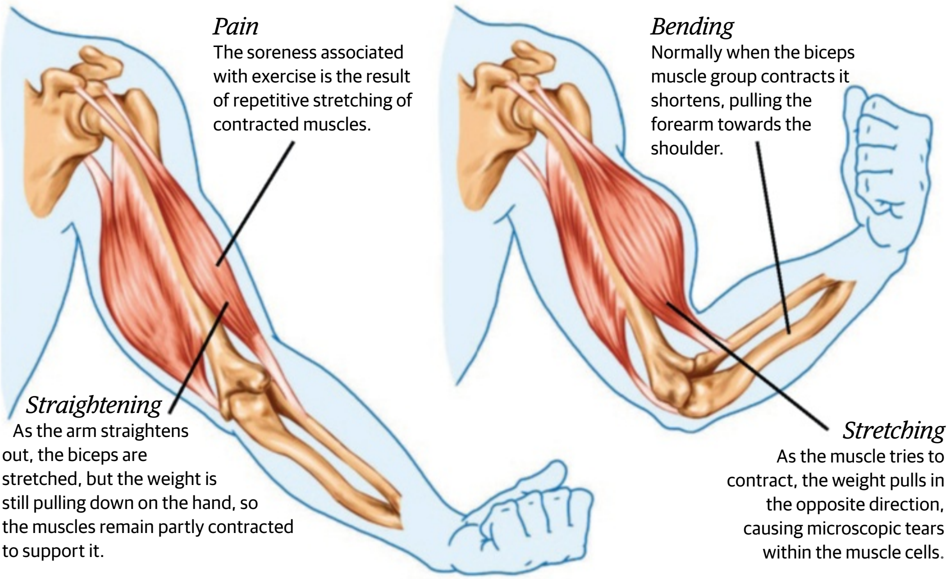
Learn what causes stiffness and pain in our muscles for days after exercise

Normally, when our muscles contract they shorten and bulge, much like a bodybuilder's biceps. But if the muscle happens to be stretched as it contracts it can cause microscopic damage.

The quadriceps muscle group located on the front of the thigh is involved in extending the knee joint, and usually contracts and shortens to straighten the leg. However, when walking down a steep slope, the quadriceps contract to support your body weight as you step forward, but as the knee bends, the muscles are pulled in the opposite direction. This tension results in tiny tears in the muscle and this is the reason that downhill running causes so much delayed-onset pain.

A muscle is made up of billions of stacked sarcomeres, containing molecular ratchets that pull against one another to generate mechanical force. If the muscle is taut as it tries to contract, the sarcomeres get pulled out of line, causing microscopic damage. The muscle gets inflamed and fills with fluid, causing stiffness and pain.

Below
What happens to your biceps when you pump iron



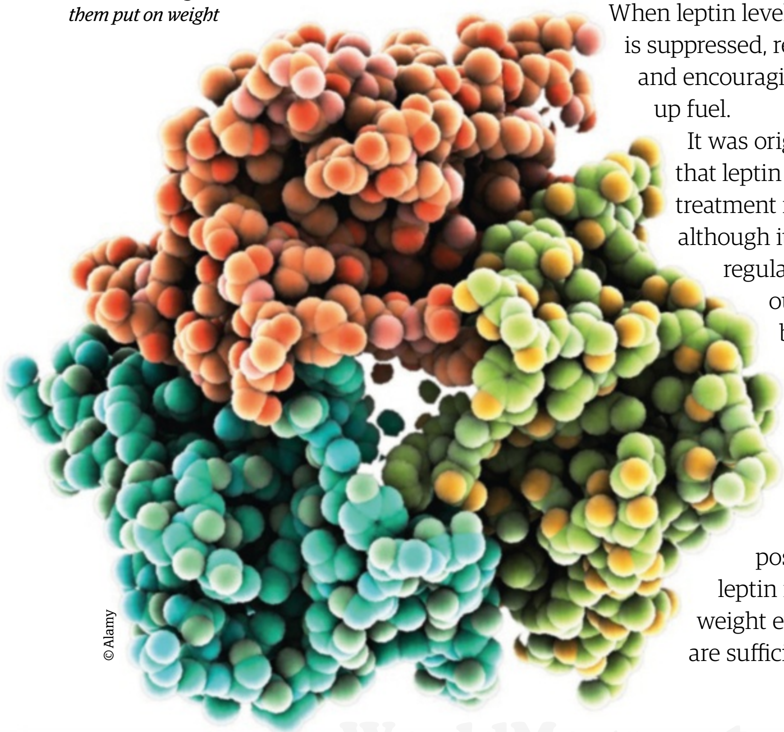
How do we know how much food to eat?

Discover how the body manages to keep track of its energy reserves

In order to know how much food to eat, the human body needs a way of assessing how much energy it currently has in storage. Leptin – more commonly known as the 'fat hormone' – essentially acts as our internal fuel gauge. It is made by fat cells and tells the brain how much fat the body contains, and whether the supplies are increasing or being used up.

Food intake is regulated by a small region of the brain called the hypothalamus, which manages many of our hormones. When fat stores run low and leptin levels drop, the hypothalamus stimulates appetite in an attempt to increase food intake and regain lost energy. When leptin levels are high, appetite is suppressed, reducing food intake and encouraging the body to burn up fuel.

It was originally thought that leptin could be used as a treatment for obesity. However, although it is an important regulator of food intake, our appetite is affected by many other factors, from how full the stomach is to an individual's emotional state or food preferences. For this reason, it's possible to override the leptin message and gain weight even when fat stores are sufficient.



Below
The leptin (LEP) gene was originally discovered when a random mutation occurred in mice, making them put on weight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How are rockets launched into space?

Understand the complex structures that help propel rockets into space

Launching a rocket takes years of planning, and the most important element is the launch pad and its attendant facilities. The launch pad cradles, fuels and powers the rocket, before it is unleashed. In the case of NASA's Space Shuttle, its rocket motors produced 3.2 million kilograms (7 million pounds) of thrust at launch. The corrosive exhaust and intense flames from the engines were channelled through a horizontal V-shaped flame trench, which consisted of two 453,600-kilogram (1 million-pound) deflectors made from steel coated with 12.7 centimetres (five inches) of heat-resistant Fondu Fyre concrete, which flakes off to disperse the intense heat.

The Space Shuttle was assembled on a moving launch platform (MLP) at the nearby vehicle assembly building (VAB) and taken to the launch pad on top of a crawler transporter. At the pad, a fixed service structure (FSS) has a lift to gain access to any level of the rocket. Anchored to it is the rotating service structure (RSS) that comprises a clean room used to load the rocket's cargo.

It took at least a month for 170 technicians and specialists to prepare, check and launch the Space Shuttle, though for less complex, unmanned rockets the timescale is a matter of days. During the countdown, all links between the FSS and the rocket were systematically released, and lastly at blast-off explosive bolts free the shuttle from the MLP. To protect the delicate components of the vehicle and the pad itself, the MLP is flooded with water at a rate of 3.4 million litres (900,000 gallons) per minute to suppress the damaging sound waves and heat produced by the engines.

Launch Complex 39A

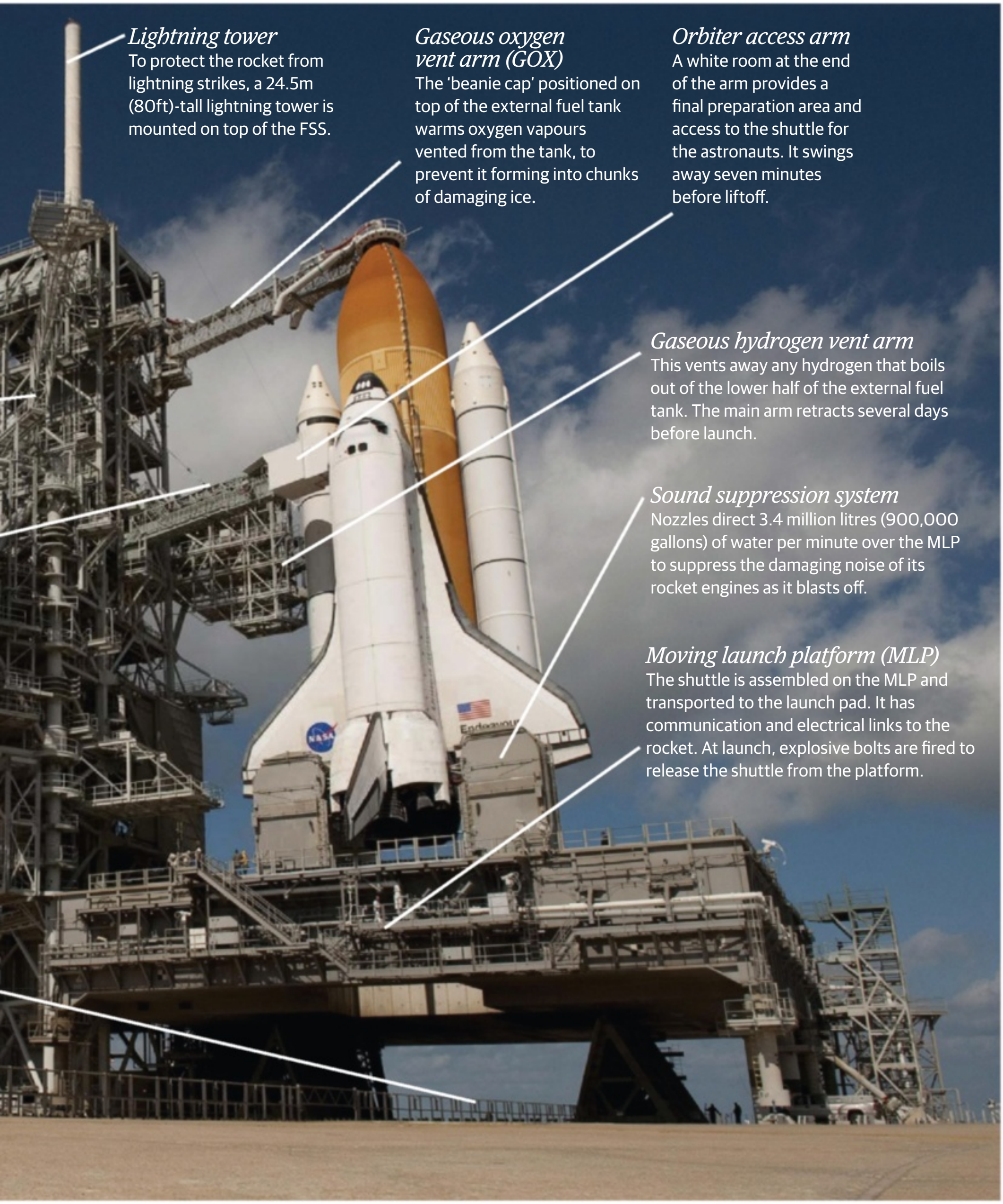
Launch Complex 39A and 39B were originally built for the Apollo moon mission's Saturn V rocket. The structures on 39B have now been demolished and 39A has been mothballed.

Rotating service structure (RSS)
This provides a clean room for the servicing and installation of payloads into the shuttle's cargo bay. The whole structure swings away prior to take-off.

Fixed service structure (FSS)
The 75m (247ft)-tall launch tower has 12 floors at 6m (20ft) intervals to gain access to the shuttle.

Emergency egress system
In an emergency astronauts can escape in seven baskets that run down slidewires to a landing zone 366m (1,200ft) away at a speed of 88km/h (55mph).

Flame trench
This 12.8m (42ft)-deep, V-shaped trench underneath the MLP is covered in high temperature-resistant concrete. It deflects the heat and flames from the rocket engines and cools the MLP with water.


Lightning tower
To protect the rocket from lightning strikes, a 24.5m (80ft)-tall lightning tower is mounted on top of the FSS.
Gaseous oxygen vent arm (GOX)
The 'beanie cap' positioned on top of the external fuel tank warms oxygen vapours vented from the tank, to prevent it forming into chunks of damaging ice.
Orbiter access arm
A white room at the end of the arm provides a final preparation area and access to the shuttle for the astronauts. It swings away seven minutes before liftoff.
Gaseous hydrogen vent arm
This vents away any hydrogen that boils out of the lower half of the external fuel tank. The main arm retracts several days before launch.
Sound suppression system
Nozzles direct 3.4 million litres (900,000 gallons) of water per minute over the MLP to suppress the damaging noise of its rocket engines as it blasts off.
Moving launch platform (MLP)
The shuttle is assembled on the MLP and transported to the launch pad. It has communication and electrical links to the rocket. At launch, explosive bolts are fired to release the shuttle from the platform.

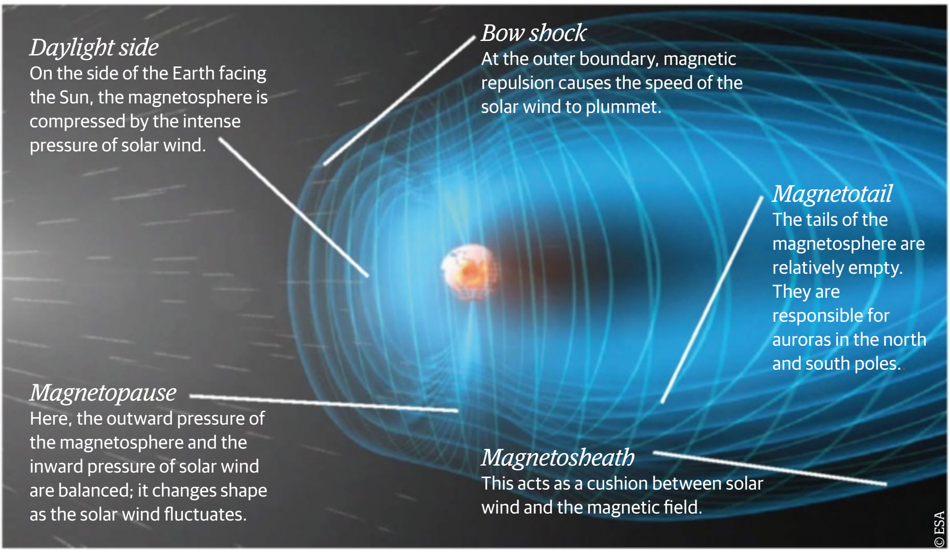
What is solar wind?

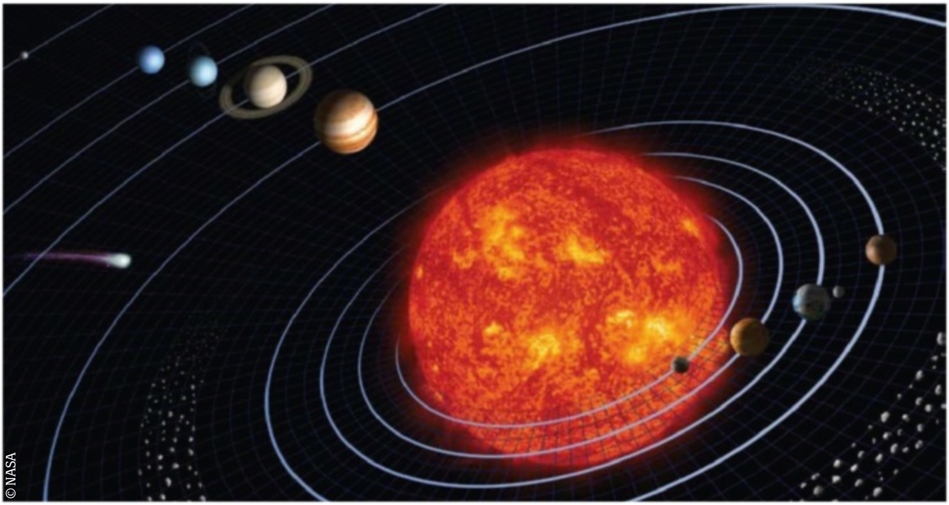
How do charged particles ejected from the Sun affect Earth's magnetic field?

Solar wind streams from the Sun at a blistering 400 kilometres (250 miles) per second. The intense heat of the corona – the outermost portion of the Sun's atmosphere – energises particles to such a level that the Sun's gravitational field can no longer hold on to them and they escape into space. Solar wind strength varies, creating space weather capable of disrupting technology, like global positioning system (GPS) satellites.

The movement of solar wind has a characteristic pattern that resembles a rope wobbling up and down – technically known as an Alfvén wave (after Hannes Alfvén). These magnetic strings can be observed as the greenish light that appears during the polar auroras. Until recently scientists have struggled to understand this unusual wave behaviour, but a new set of models – based on similar waves generated by polarised light – might enable us to understand, and even predict, future fluctuations in solar wind.

Below
How the charged protons and electrons in the solar wind deform the magnetosphere

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Do all planets in our Solar System orbit the same way?

Discover how the planets' orbits relate to the Solar System's formation

All of the planets and nearly all asteroids in the Solar System orbit in the same direction (anticlockwise if you were looking down on the Solar System from way above the Earth's north pole) – and they all orbit close to the same flat plane as well. This is because they, along with the Sun itself, all formed from the same protoplanetary nebula – a cloud of interstellar gas and dust that began to collapse under its own gravity around 5 billion years ago.

As the nebula became more concentrated, it flattened out and began to spin more quickly, and the Sun, asteroids and planets then condensed out of different parts of this flattened disc.

The few objects that follow backward, or retrograde, orbits – and those whose orbits are sharply tilted to the lane of the Solar System – tend to be the result of close encounters with the disruptive gravity of a giant body like Jupiter.

What's inside the Sun?

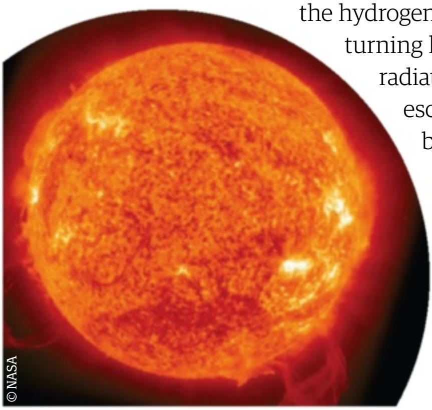
At the heart of the giant star

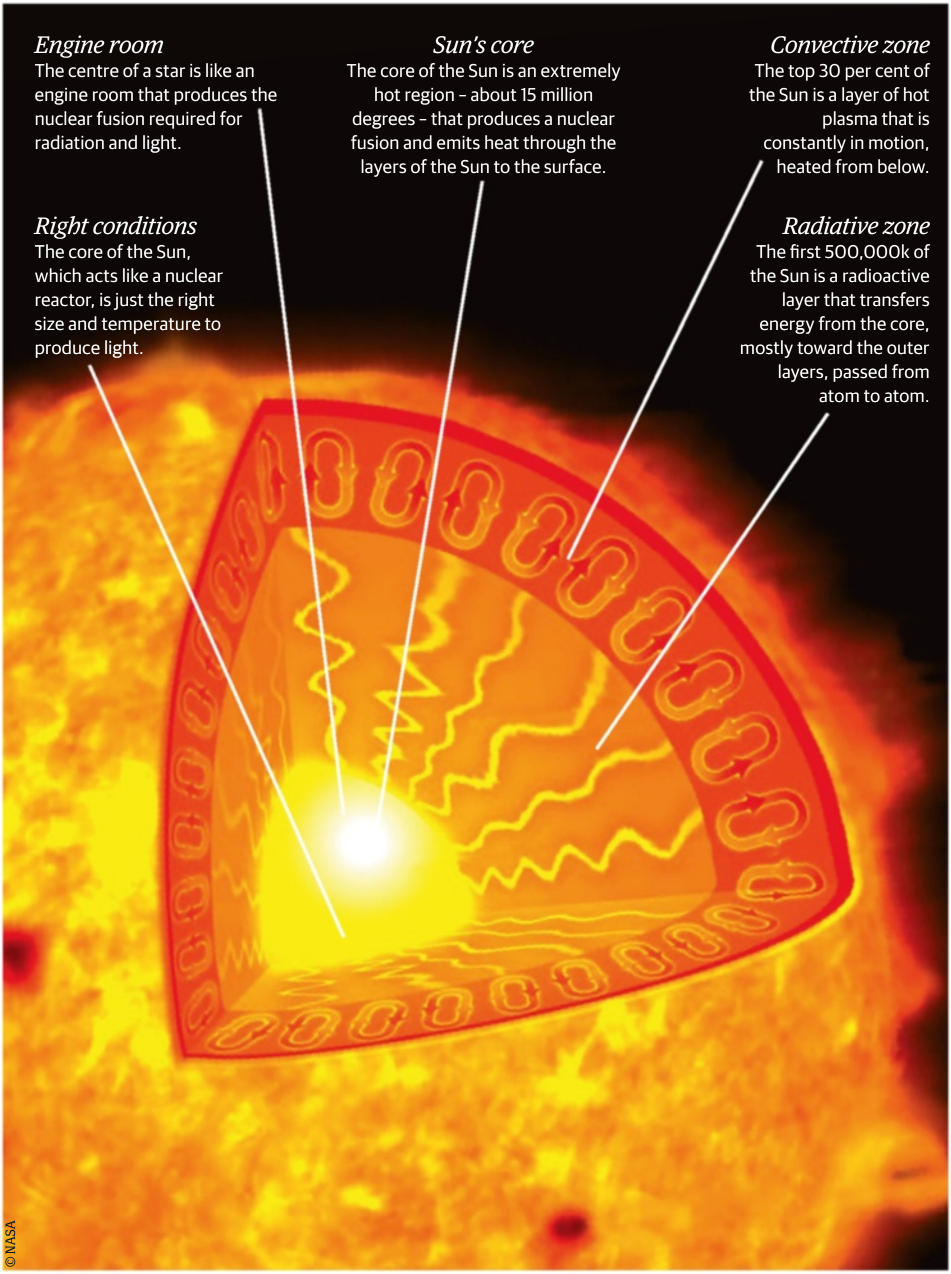
A celestial wonder, the Sun is a huge star formed from a massive gravitational collapse when space dust and gas from a nebula collided, It became an orb 100 times bigger and weighing over 300,000 times that of Earth. Made up of 70 per cent hydrogen and about 28 per cent helium (plus other gasses), the Sun is the centre of our solar system and the largest celestial body anywhere near us.

"The surface of the Sun is a dense layer of plasma at a temperature of 5,800 degrees kelvin that is continually moving due to the action of convective motions driven by heating from below," says David Alexander, a professor of physics and astronomy at Rice University. "These convective motions show up as a distribution of what are called granulation cells about 1,000 kilometres across and which appear across the whole solar surface."

At its core, the Sun's temperature and pressure are so high and the hydrogen atoms are moving so fast that it causes fusion, turning hydrogen atoms into helium. Electromagnetic radiation travels out from the Sun's core to its surface, escaping into space as electromagnetic radiation, a blinding light, and incredibly high levels of solar heat. In fact, the core of the Sun is actually hotter than the surface, but when heat escapes from the surface, the temperature rises to over 1-2 million degrees. Professor Alexander explained that astronomers do not yet fully understand why this giant star's atmosphere is so hot, but they think that it has something to do with magnetic fields.

Below
A solar flare is a rapid release of energy in the solar atmosphere resulting in localised heating of plasma, acceleration of electrons and protons to high energies and expulsion of material into space




Engine room
The centre of a star is like an engine room that produces the nuclear fusion required for radiation and light.
Sun's core
The core of the Sun is an extremely hot region – about 15 million degrees – that produces a nuclear fusion and emits heat through the layers of the Sun to the surface.
Convective zone
The top 30 per cent of the Sun is a layer of hot plasma that is constantly in motion, heated from below.
Right conditions
The core of the Sun, which acts like a nuclear reactor, is just the right size and temperature to produce light.
Radiative zone
The first 500,000k of the Sun is a radioactive layer that transfers energy from the core, mostly toward the outer layers, passed from atom to atom.

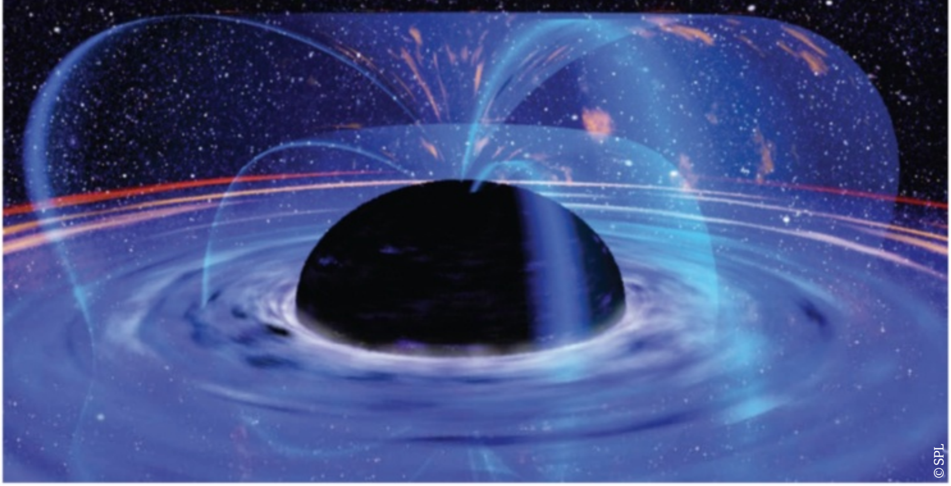
What is an event horizon?

What makes these a black hole's point of no return?

There are three basic elements to a black hole. There's the singularity itself, at the heart of a black hole and made of stellar matter compressed to an infinite density. Outside the singularity is the black hole's interior space, where the rules of physics as we know them get bent and broken, and where space and time are stretched and compressed like putty. If your spacecraft has entered a black hole's interior space, then it's too late for you. You're past the third component: the event horizon.

Also known as the Schwarzschild radius, this is the part that lets us know where black holes are by outlining them in black. It marks the point of no return for anything falling beyond it, as to re-cross it would require travelling faster than the speed of light, which – as far as we know – is impossible.

Event horizons aren't solely attributed to black holes – they're just a noteworthy phenomenon that possesses them. According to some theories governing the expansion of the cosmos, there are areas that won't ever be observable because light will never reach us from them. So the boundary limit at which we can observe the universe is also an event horizon.



Who lays claim to the Moon?

Discover where Earth's nations stand on lunar sovereignty

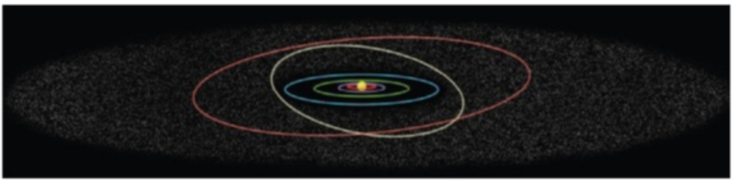
According to the 1967 United Nations Outer Space Treaty, 'Outer Space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.' This treaty has been ratified by 62 countries, including the world's leading space powers, and was intended to apply to commercial and private operations as well. In contrast, the 1979 International Moon Treaty, drawn up specifically to prevent private claims to lunar real estate, has only been ratified by a handful of nations. But you can rest assured that any private operator who tried to claim parts of the Moon would at least have to plant a flag there first!


© NASA

Where is the Kuiper belt?

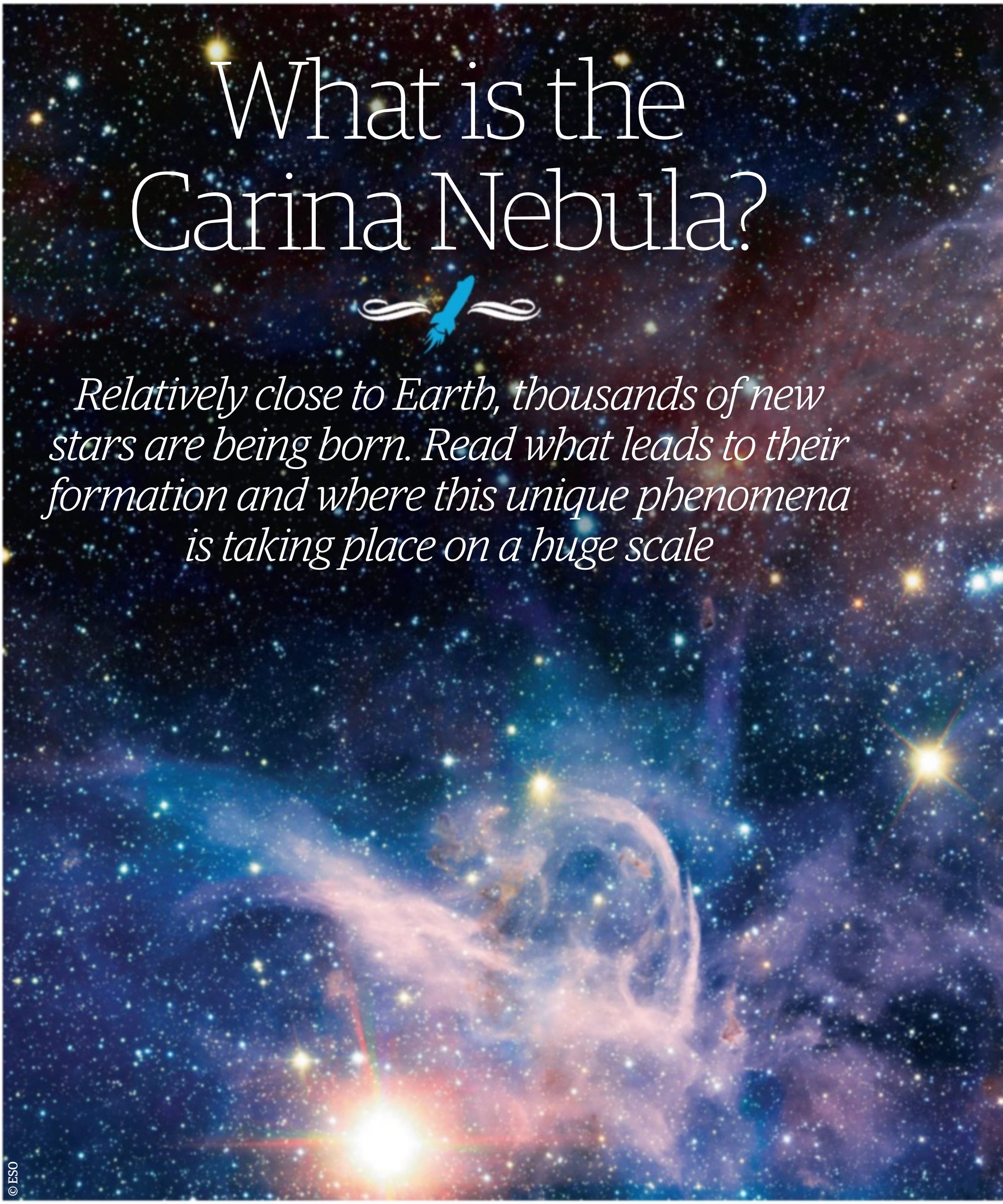
Where is this gigantic asteroid field and cloud of icy particles?

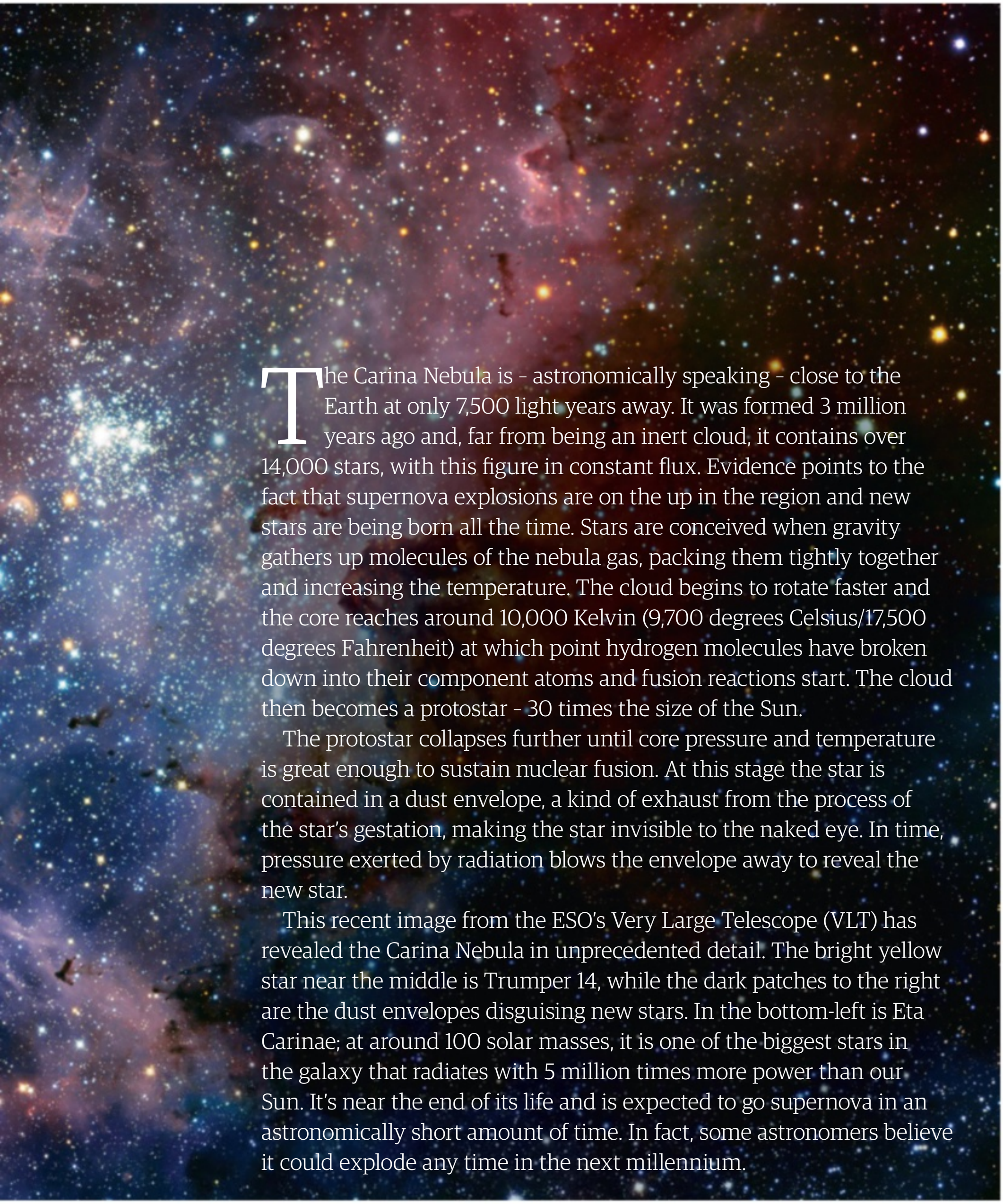
Beyond the orbit of Neptune lies a wide belt of the remnants from the construction of our Solar System. The Kuiper belt contains hundreds of thousands of icy particles thought to be up to 60 miles in diameter, along with up to a trillion smaller comets. But the Solar System doesn't end there – it is entombed in an almost perfect sphere of ice, the Oort Cloud. Lying on the boundaries of interstellar space, this shell is thought to contain up to 2 trillion icy bodies.



What is the Carina Nebula?

Relatively close to Earth, thousands of new stars are being born. Read what leads to their formation and where this unique phenomena is taking place on a huge scale





The Carina Nebula is – astronomically speaking – close to the Earth at only 7,500 light years away. It was formed 3 million years ago and, far from being an inert cloud, it contains over 14,000 stars, with this figure in constant flux. Evidence points to the fact that supernova explosions are on the up in the region and new stars are being born all the time. Stars are conceived when gravity gathers up molecules of the nebula gas, packing them tightly together and increasing the temperature. The cloud begins to rotate faster and the core reaches around 10,000 Kelvin (9,700 degrees Celsius/17,500 degrees Fahrenheit) at which point hydrogen molecules have broken down into their component atoms and fusion reactions start. The cloud then becomes a protostar – 30 times the size of the Sun.

The protostar collapses further until core pressure and temperature is great enough to sustain nuclear fusion. At this stage the star is contained in a dust envelope, a kind of exhaust from the process of the star's gestation, making the star invisible to the naked eye. In time, pressure exerted by radiation blows the envelope away to reveal the new star.

This recent image from the ESO's Very Large Telescope (VLT) has revealed the Carina Nebula in unprecedented detail. The bright yellow star near the middle is Trumper 14, while the dark patches to the right are the dust envelopes disguising new stars. In the bottom-left is Eta Carinae; at around 100 solar masses, it is one of the biggest stars in the galaxy that radiates with 5 million times more power than our Sun. It's near the end of its life and is expected to go supernova in an astronomically short amount of time. In fact, some astronomers believe it could explode any time in the next millennium.

Is it possible to alter Earth's orbit?

Could anything knock our planet out of its orbit?

Yes, it's possible, but the impact required would be so large that the Earth would likely be destroyed. Many astronomers think that around 4.5 billion years ago, when the Solar System was forming, the Earth got a 'big whack', which resulted in our moon being formed. According to this theory, a Mars-sized object struck the early Earth. At this stage in the Solar System's evolution both bodies would have been made mainly of molten material that had not yet solidified. Their iron-rich cores merged, while parts of their outer layers were vaporised and thrown into orbit around the Earth. This material eventually coalesced to form our rocky moon. The Earth gained angular momentum, and its orbit may have changed slightly.

Why is Pluto not a planet?

Understand the decisions that led to Pluto's re-classification

Well, it's still a planet of sorts. Since 2006 Pluto has been classified by the International Astronomical Union as a 'dwarf planet'. In recent decades, powerful telescopes have enabled astronomers to discover several Pluto-sized objects beyond Neptune's orbit, and there are probably lots more out there. So, either they had to expand the list of planets (which would mean you'd have to remember a lot more for your science exams) or it was time to come up with an official definition of what counts as a planet.

© SPL

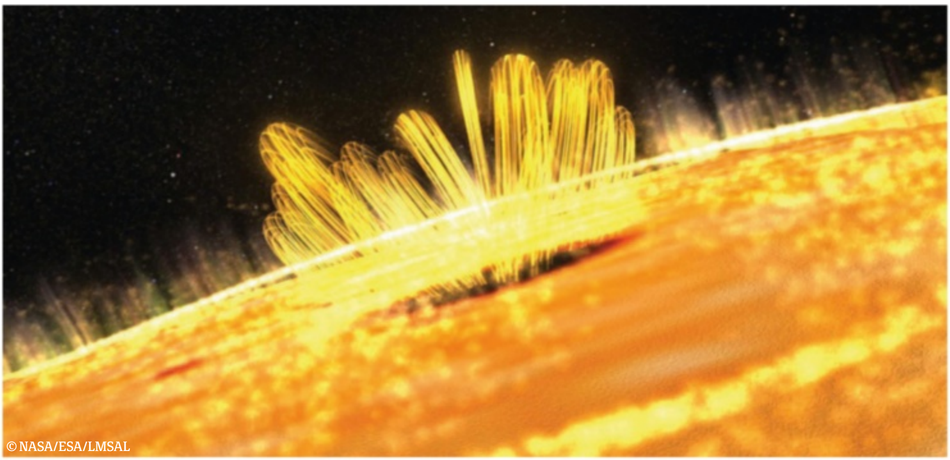
How are solar tsunamis caused?

The mega-waves of energy that tear from one end of the Sun to the other

Solar tsunamis are surges of material sent crashing across the Sun as the result of a solar flare being launched into space. They can travel at speeds up to 1.6 million km (1 million miles) per hour. These solar tsunamis are made of hot plasma and magnetic energy. The first was observed by Gail Moreton in 1959, and since then several more studies have been conducted by the Solar and Heliospheric Observatory (SOHO) and the Solar Terrestrial Relations Observatory (STEREO) spacecraft, both of which orbit the Earth.

Solar tsunamis are formed when the Sun emits a coronal mass ejection (CME) – a massive burst of solar wind commonly associated with solar flares. Around the ejection point, a circular wave extends outwards in all directions and travels across the surface of the Sun at a super-fast rate. In February 2009, the two STEREO spacecraft watched as a billion-ton cloud of gas was hurled off the surface of the Sun from a CME. The result of this ejection was a massive solar tsunami that towered 100,000km (60,000 miles) high and which sped across the star's surface at about 900,000km (560,000 miles) per hour. It was estimated to contain the same energy as 2.4 million megatons of TNT.

Below
Solar tsunamis can be thrown away from the exit point of a solar flare as it's ejected into space



Why does the Earth spin?

Find out why our planet has rotational movement

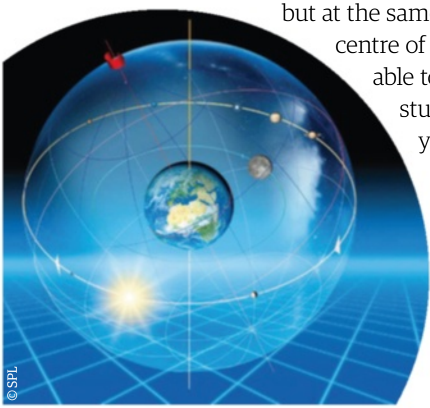
The story of why the Earth spins goes back to the formation of the Solar System. Roughly 4.7 billion years ago, the Solar System was a large swirling cloud of dust and gas. Over time this gradually coalesced into stars and planets, being drawn into these shapes by gravity. Being pulled inwards increased the angular momentum of the various bodies, and made them rotate faster.

The law of inertia states that anything stationary or moving with a constant speed wants to continue doing so until it is acted upon by another body/force. Considering the Earth rotates in space, which is a vacuum, there is nothing to drastically slow the Earth down, which is why it continues to spin. Interestingly, early in its formation, the Earth spun up to five times faster than it does now – so it has slowed down.

The culprit is the moon, via something known as tidal locking. To understand tidal locking, imagine you and a friend both pull on a rope, but at the same time you spin in a circle around a pivot at the centre of the rope. As you tug harder, you are eventually able to spin less and less fast. Eventually, you will be stuck simply pulling on the rope, unable to move as your pulling force is too great; this is essentially what happened between Earth and the moon.

As the moon orbits Earth it exerts a pull on the planet, responsible for causing tides. The Earth is much bigger so continues to spin freely, but the moon's rotation now matches the time it takes to complete one orbit. Small as it is, the moon will continue to effect the Earth and, in millions of years, a day could last up to 26 hours.

Below
CG image of Earth showing its rotation compared to the rest of the Solar System



The Earth's rotation

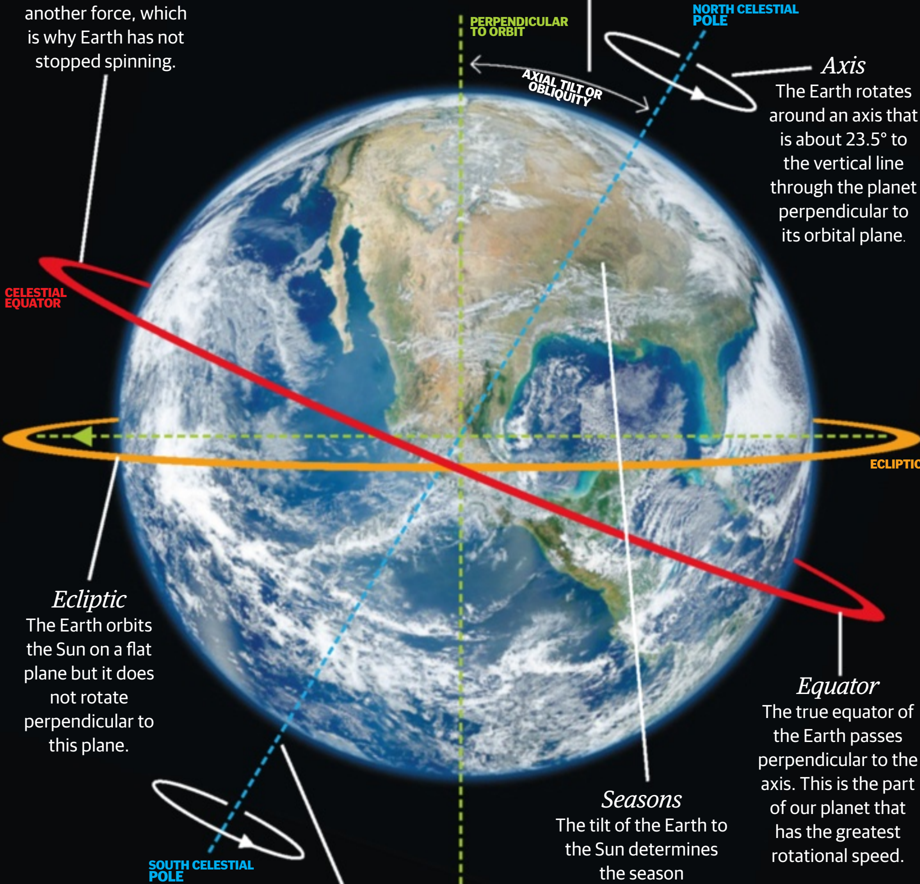
Understand the key factors behind how the Earth rotates

Inertia

The law of inertia states an object will continue to move unless acted upon by another force, which is why Earth has not stopped spinning.

Angle

The angle of the Earth's rotation has not always been the same; some research suggests it changes up to 1° every million or so years.



Axis

The Earth rotates around an axis that is about 23.5° to the vertical line through the planet perpendicular to its orbital plane.

Ecliptic

The Earth orbits the Sun on a flat plane but it does not rotate perpendicular to this plane.

Equator

The true equator of the Earth passes perpendicular to the axis. This is the part of our planet that has the greatest rotational speed.

Seasons

The tilt of the Earth to the Sun determines the season experienced in each hemisphere, with a tilt towards or away leading to hot and cold seasons, respectively.

Poles

The poles experience little to no rotational force, and thus can experience prolonged daylight and darkness in summer and winter, respectively.

X3 © NASA

Why is the surface of Mars red?

How the red planet got its iconic colour

The red colour that we usually see in images of Mars is actually the result of iron rusting. Rocks and soil on the surface of Mars contained a dust composed mostly of iron and small amounts of other elements such as chlorine and sulphur. The rocks and soil were then eroded by wind and the resulting dust was blown across the planet's surface by the activity of ancient volcanoes. Recent evidence suggests dust was also spread across Mars by water, a theory backed up by the presence of channels and ducts across the planet's surface.

The iron contained within the dust then reacted with the oxygen in the atmosphere, producing the distinctive red rust colour, while the sky appears red because storms carried the red dust high up into the planet's atmosphere. This dusty surface, which is between a few millimetres and two metres deep, also sits above a layer of hardened lava which is mostly composed of basalt. The concentration of iron that is found in this basalt is much higher than it is in basalt on Earth, and this also contributes to the red appearance of Mars.

How do ocean tides work?

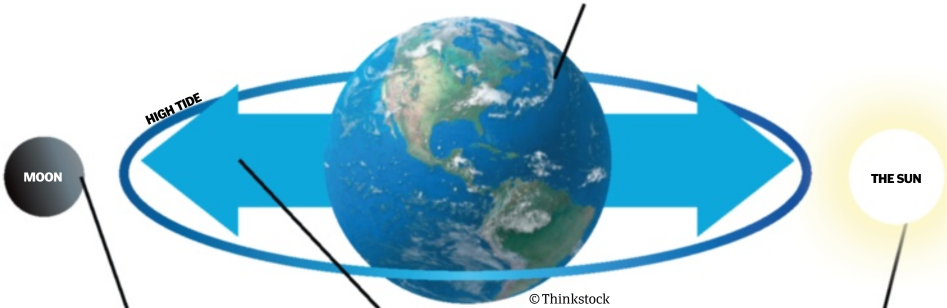
Gravitational forces tip ocean waters like a bathtub

You're sitting on a beach, cooking a barbecue with the family. The Sun sets in the distance. You look around and – like the famous scene from *Chitty Chitty Bang Bang* – you're surrounded by water. The phenomenon of ocean tides is caused by gravitational forces as the Earth moves around the Sun, and the moon moves around the Earth.

The effect of tides as we see them is due to gravity pulling water to one side of the Earth or another. It helps to think of a giant bathtub, with vast bodies of water being moved as the tub is tipped.

Earth

There are two scientific principles at work, says Iheanyi N Osondu PhD, an associate professor of geography at Fort Valley State University in Georgia. "The rotation of the Earth produces the Coriolis effect," he says. "The movement of currents of water and air is affected by Coriolis. Ferrell's law states that any object or fluid moving horizontally in the northern hemisphere is deflected to the right of its path of motion regardless of compass direction. In the southern hemisphere, it is deflected towards the left."



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Moon pull

A second reason for ocean tides rising and lowering: the ocean tends to bulge on the side of the Earth that is closest to the moon. "The moon makes one complete rotation round the Earth every 29 and a half days," says Osondu. "On the other hand, the Sun also influences the tides. It should, however, be noted that the moon has a greater influence on tides than the Sun because it is nearer, even though the Sun is much larger."

Gravitational pull

It helps to think of the ocean as a giant bathtub filled with water: if you tipped the bathtub to one side, the water would rise. In the ocean, the water levels change when gravity pulls water to one side of the Earth, which causes the water level to lower on the other side.

Tides

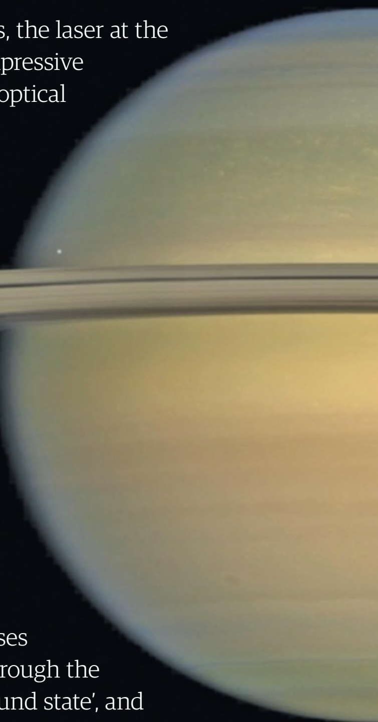
There are also three kinds of tides on the planet, says Osondu. Diurnal is when the tide rises and lowers once per day, and is common in the Gulf of Mexico. Semidiurnal, common in the Atlantic coasts, has two similar tides per day. Mixed tides, where there are two dissimilar tides per day, are common in the Pacific coasts.

Why does Saturn have rings?

The mysteries of how Saturn's rings were formed are only now revealing themselves to us…

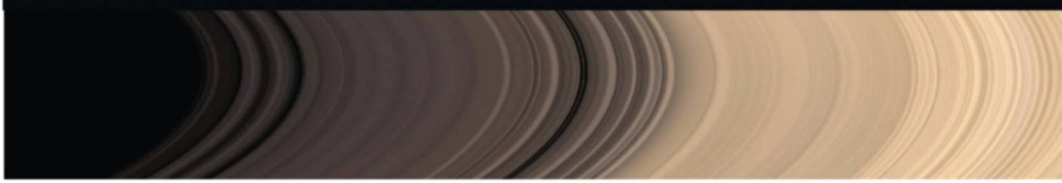
At least 60 times more powerful than its predecessors, the laser at the National Ignition Facility (NIF) in California is an impressive feat of precision engineering. It contains the largest optical instrument ever built, 7,500 flash-lamps, 97 kilometres (60 miles) of mirrors and fibre optics, and is roughly the size of three football pitches.

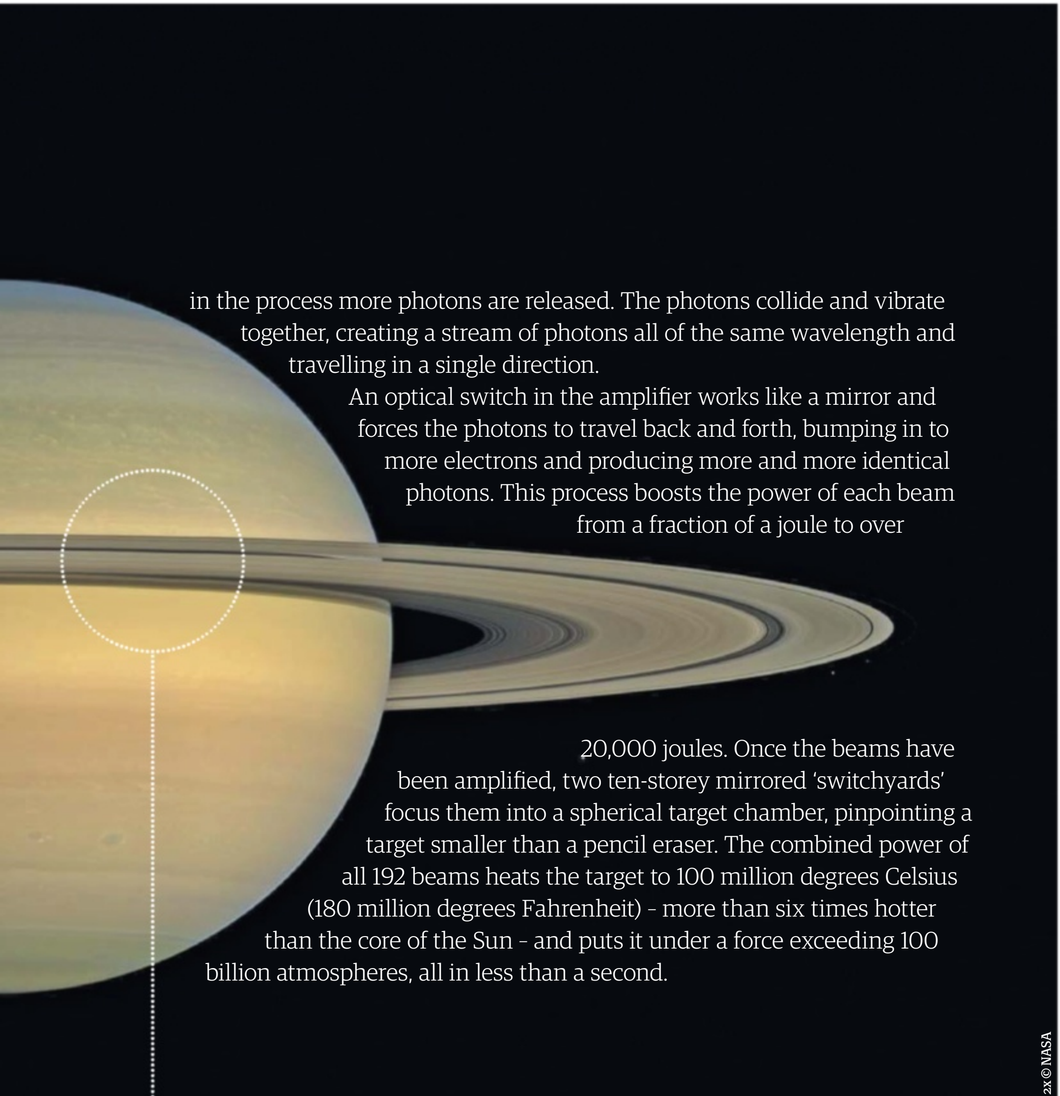
At the master oscillator of the NIF, a low-energy pulse of photons is generated using an optical



fibre laser. To amplify the laser pulse it is broken down into 192 separate beams; these are then carried through fibre-optic cables to a series of amplifiers.

Powerful white flash-lamps are used to energise sheets of neodymium-impregnated phosphate glass, which energises electrons in the neodymium atoms. As the photons pass through the amplifier they cause the electrons to drop back to their 'ground state', and

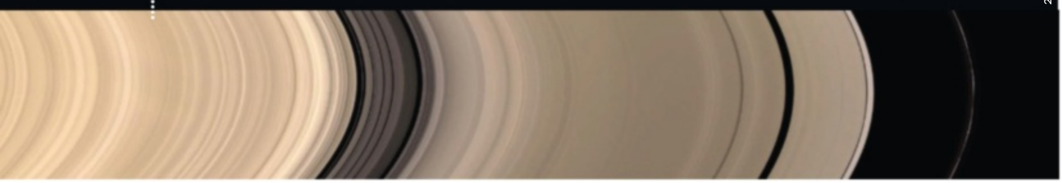




in the process more photons are released. The photons collide and vibrate together, creating a stream of photons all of the same wavelength and travelling in a single direction.

An optical switch in the amplifier works like a mirror and forces the photons to travel back and forth, bumping in to more electrons and producing more and more identical photons. This process boosts the power of each beam from a fraction of a joule to over 20,000 joules. Once the beams have been amplified, two ten-storey mirrored 'switchyards' focus them into a spherical target chamber, pinpointing a target smaller than a pencil eraser. The combined power of all 192 beams heats the target to 100 million degrees Celsius (180 million degrees Fahrenheit) – more than six times hotter than the core of the Sun – and puts it under a force exceeding 100 billion atmospheres, all in less than a second.

2x © NASA



What is the Goldilocks Zone?

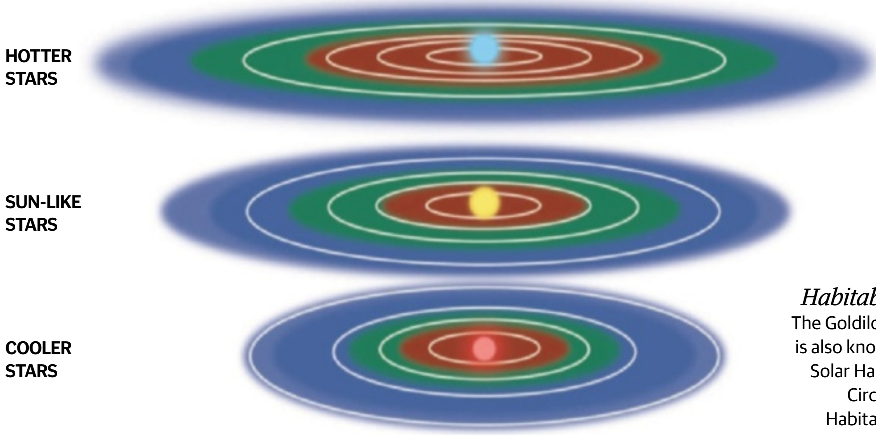
Life-sustaining planets require such exacting standards that scientists call the area they occupy 'the Goldilocks Zone'

The Goldilocks Zone is an area 'just right' for a life-sustaining planet – the perfect distance from a star with a surface neither too hot nor too cold. It is an intersection of life-sustaining regions within both a solar system and a galaxy. Astronomers believe that the Goldilocks Zone ranges from 0.725 to three astronomical units (each about 150 million kilometres, or the mean distance between the Earth and the Sun).

Recently some planetary bodies have come close to fitting the bill. The April 2007 discovery of Gliese 581c in the Libra constellation, for example, seemed promising until further research proved it was too hot. However, a nearby planet, Gliese 581d, may turn out to be just right. At the same time, the definition of the Goldilocks Zone is expanding as scientists discover life on Earth in places previously thought too extreme to sustain it.

Location
Solar systems must be in the right place in the galaxy to sustain the formation of terrestrial planets, but not receive high doses of radiation.

Distance from the Sun
If the Earth had formed just a few percentage points closer or further from the Sun, it would be either covered in ice or have no oceans.

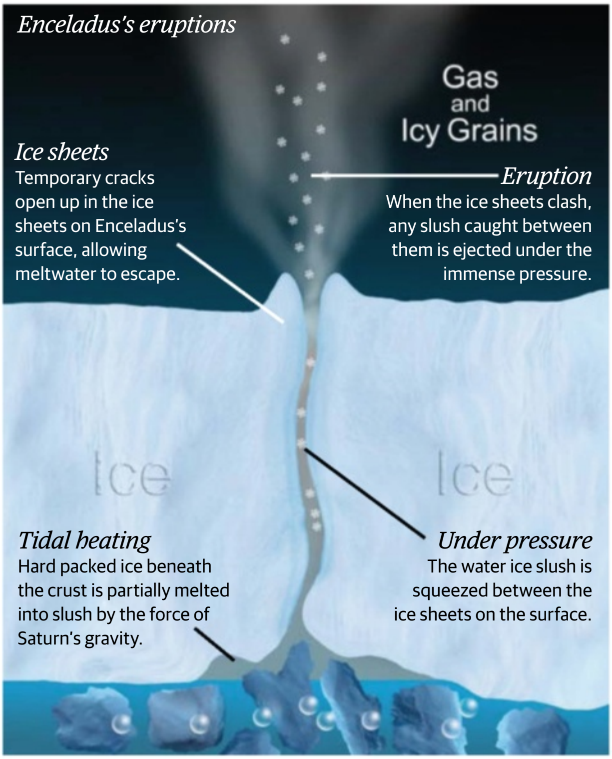


Habitable zone
The Goldilocks Zone is also known as the Solar Habitable or Circumstellar Habitable Zone.

How do ice volcanoes form?

Saturn's freezing moon Enceladus has volcanoes, but they're not what you'd expect

They're known as cryovolcanoes, and though scientists don't have cast-iron proof that volcanoes spouting ice from a sub-zero caldera exist on Enceladus, there is strong evidence for it. The flyover by Cassini two years ago revealed jets spurting from four cracks along the moon's surface, named Alexandria, Cairo, Baghdad and Damascus. The eruptions were so high that they could easily be seen in profile from space.



Volcanoes found on Earth and also Jupiter's moon Io spout silicate lava that is heated by the pressure beneath the crust. Ice volcanoes work in a similar way: scientists believe that subterranean geological activity on Enceladus warms the freezing surface into a slush of water, ice and organic compounds, which is then ejected out by force through the surface by ice sheets grinding up against one another.

Enceladus has an elliptical orbit similar to our moon, so as Saturn's gravity pulls unevenly at Enceladus it creates a bulge that generates the friction and heat necessary to cause this previously unheard-of phenomenon.


Evolution
Developments in engineering have allowed us to progress from wooden contraptions to multimillion pound airliners that can transport hundreds of people around the globe.
Wings
The wings of a plane generate lift, and can manipulate airflow so there's a lower pressure area above the wing.
Aerodynamic
Planes are shaped in a way to make them as aerodynamic as possible, helping to reduce drag.
Engines
A plane has to be able to create enough forward force – or thrust – to counteract the force of gravity.
© Thinkstock

How do planes fly?

Take to the skies and discover how hundreds of tons of metal can remain airborne

For millennia, would-be aviators knew bird flight had something to do with wing structure, but were clueless regarding the details. As it turns out, the shape of a wing is optimised to generate lift, an upward force caused by manipulating airflow. A wing has a rounded leading edge with a slight upward tilt, a curved topside, and a tapered trailing edge pointing downward. This shape alters the flow of air molecules into a downward trajectory. This results in – as Newton put it in his Third Law of Motion – "an equal and opposite reaction." When the wing pushes the air molecules down, the molecules push the wing up with equal force. The airflow also creates a lower pressure area above the wing, which sucks the wing up.

Constructing wings is the easy part. To fly, you need to generate enough forward force – or thrust – to produce the necessary lift to counteract gravity. The Wright Brothers accomplished this by linking a piston engine to twin propellers. A plane propeller is simply a group of rotating wings shifted 90 degrees, so the direction of lift is forwards rather than upwards. In 1944, engineers upgraded to jet engines, which produce much greater thrust by igniting a mixture of air and fuel, and expelling hot gasses backward.

A pilot controls a plane by adjusting movable surfaces on the main wings, as well as smaller surfaces and a wing-like rudder on the tail. By changing the shape and position of these structures, the pilot varies the lift force, acting on the different ends of the plane to essentially pivot the plane along three axes: its pitch (up or down tilt of the nose), roll (side to side rotation), and yaw (turn to the left or right).

Engineers keep planes as light and aerodynamic as possible. Modern fighter jets are manufactured from super-strong, lightweight composite material, applied in layers to form precise, aerodynamic shapes.

What forces act on an aeroplane in flight?

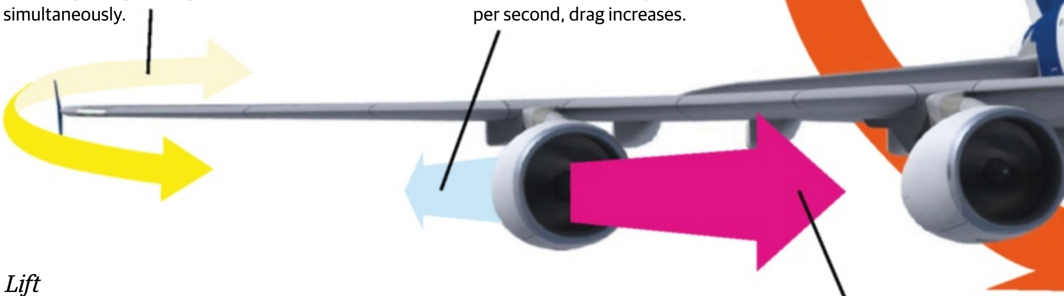
More than a century after the Wright Brothers, physicists are still debating exactly how wings work. Accessible explanations for the rest of us can't help but leave things out, and some common answers are flat-out wrong.

The crucial thing to understand is that air is a fluid, and that wings alter the flow of that fluid. The top and bottom of the wing both deflect air molecules downwards, which results in an opposite upward force. In the typical airfoil design, the top of the wing is curved. Flowing air follows this curve, causing it to leave the wing at a significant downward angle. This also generates a low-pressure area above the wing, which helps pull it up.

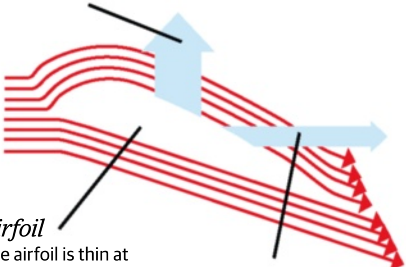
Long, skinny wings are more efficient because they produce minimal drag proportional to lift. But they're also fragile and slow to manoeuvre. In contrast, stubby wings offer high agility and strength, but require more thrust to produce lift.

Yaw
Planes have a vertical tail rudder, which is similar to the rudder on a boat. When you tilt the rudder to the left, rushing air will pivot the tail to the right. To turn successfully, it's necessary to adjust the yaw and roll simultaneously.

Drag
The mass of molecules in the air creates resistance to the forward-moving plane, causing backward drag that works against the thrust. As the plane speeds up and encounters more air particles per second, drag increases.



Lift
The air flowing over the top has further to go, so must travel quicker to keep up with the air below.

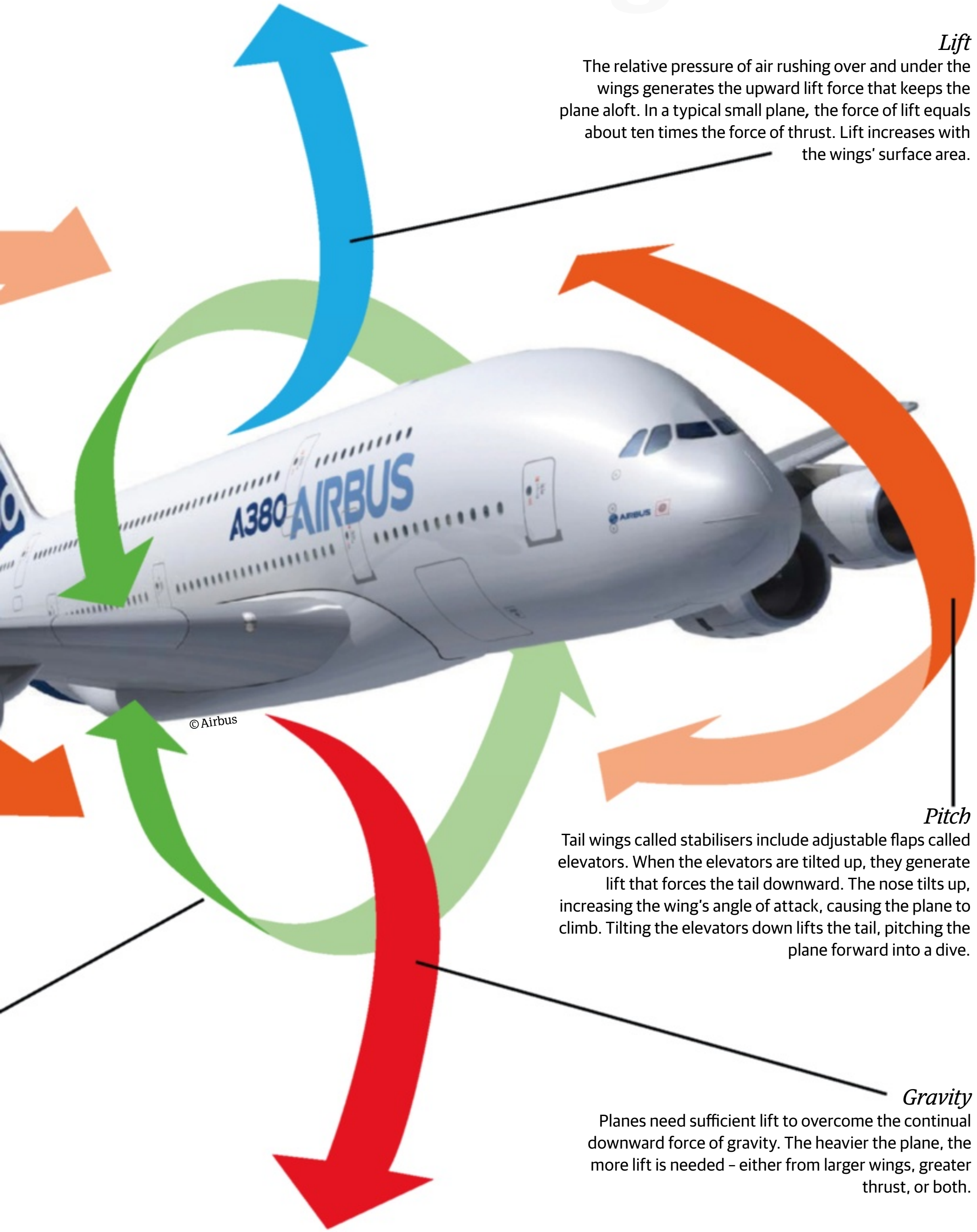


Airfoil
The airfoil is thin at the front, thicker in the middle and thinner again at the rear end.

Drag
Air resistance pulls the aircraft in the opposite directio

Thrust
The forward thrust of the plane, generated by propellers, jet engines or rockets, counteracts drag and moves the wings through the air to generate lift.

Roll
To roll the plane, the hinged wing surfaces, called ailerons, have to be adjusted. To roll right, the aileron on the right wing has to be raised, which reduces lift, while simultaneously lowering the aileron on the left wing, which increases lift. The left wing rises and the right wing drops, rolling the plane to the right.



Lift

The relative pressure of air rushing over and under the wings generates the upward lift force that keeps the plane aloft. In a typical small plane, the force of lift equals about ten times the force of thrust. Lift increases with the wings' surface area.

Pitch

Tail wings called stabilisers include adjustable flaps called elevators. When the elevators are tilted up, they generate lift that forces the tail downward. The nose tilts up, increasing the wing's angle of attack, causing the plane to climb. Tilting the elevators down lifts the tail, pitching the plane forward into a dive.

Gravity

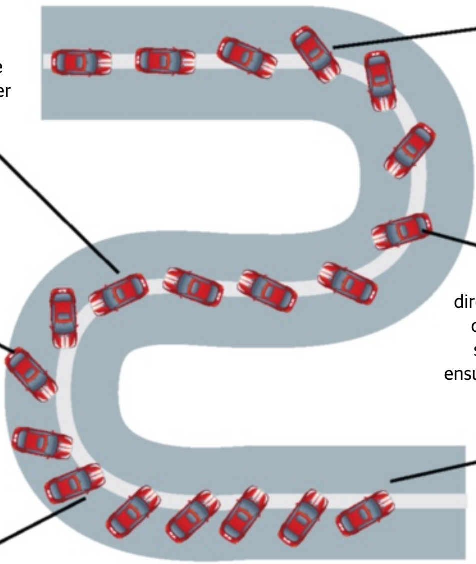
Planes need sufficient lift to overcome the continual downward force of gravity. The heavier the plane, the more lift is needed – either from larger wings, greater thrust, or both.

How do you drift in a car?

It looks like just a cool trick, but drifting involves driving precision and unique physics

At first glance it may seem like a car is wildly out of control, but drifting is a highly technical form of driving involving the calculated shifting of balance of a vehicle, and has developed into one of the fastest-growing motorsports in the world. The idea behind it is to maintain a state of oversteer while negotiating a series of corners. A driver will call on constant, quick adjustments to the throttle, brakes, clutch, gears and steering. Only cars with rear-wheel drive can be successfully drifted, and these are placed under high stress, requiring strengthened components like a clutch and handbrake. These cars tend to get through a good number of tyres.

Drifting is loud and creates lots of tyre smoke and the practice is forbidden on public roads. Specially organised drift events let enthusiasts practise and compete to complete a course with the best drifts according to a panel's criteria.



1. Approach
Head into a corner with high momentum, with plenty of revs. Steer hard into the corner to send the rear of the car sliding.

2. Counter-steer
Once the car is pointing directly into the inside corner of the bend, apply counter-steer, as well as throttle, to ensure the car doesn't spin off.

3. Steering adjustment
From here, minor tweaks to steering and throttle will keep the car balanced in a state of oversteer through the corner. Dab the throttle, keeping the revs high to maintain control.

4. Swing round
As the car leaves the first corner and you prepare for the second, apply full throttle under opposite lock in order to push the rear of the car swinging round to the other side.

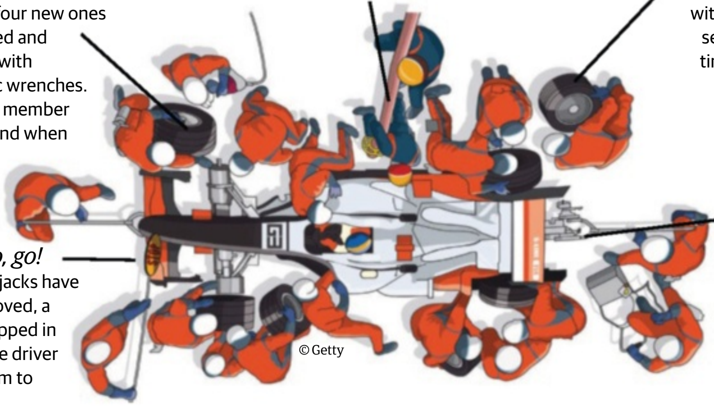
5. Next corner
With the car now entering the second corner with the rear swung to the other side, apply counter-steer again, aiming for the end of the corner.

6. Exit
You can maintain a drift even on a straight, but to exit a drift come off the power and aim your wheels forward.

4. Wheels on
Once the four old wheels are taken off – each by a dedicated handler – four new ones are installed and re-affixed with pneumatic wrenches. Each crew member raises a hand when finished.

3. Fuel hose
A dedicated team accesses the fuel port and inserts a high-speed hose to quickly refill its tank. This no longer occurs in F1 as all cars are fully fuelled to the end of the race.

2. Wheels off
All four wheels are removed with pneumatic wrenches within just a couple of seconds at the same time as the fuel hose is inserted.



© Getty

5. Go, go, go!
When the jacks have been removed, a sign is dropped in front of the driver telling them to accelerate.

1. Jack
The moment the car is stationary in the pit a series of jacks is used to lift it off the ground. This allows the tyres to be changed.

What happens in an F1 pitstop?

How are these complex repairs made so rapidly under such pressure?

A pitstop is a motorsport operation where a racing car – such as those used in Formula 1 – is refuelled, fixed, adjusted or gets a new driver. In an F1 context, a pitstop generally entails changing the car's wheels and fixing any damage.

Pitstops are carried out in the pits, a segment of track that runs parallel to the main circuit's starting grid, and is broken down into a series of bays. Each bay is assigned to a team, with a bay consisting of an internal garage and an external, pit-side operations area.

When a car needs attention, the team's communications crew calls the vehicle in to the pits, which involves the driver completing their current lap and then entering the pit lane. For safety, a set speed limit is imposed within the pit lane. The driver then proceeds down the lane and is flagged into their bay by a sign-waving crew member.

As soon as the driver is stationary, operations can begin. Once any repairs and adjustments have been completed, the car is released to travel to the end of the pit lane and then the circuit proper, where it merges back into the racing pack.

How do clutches work?

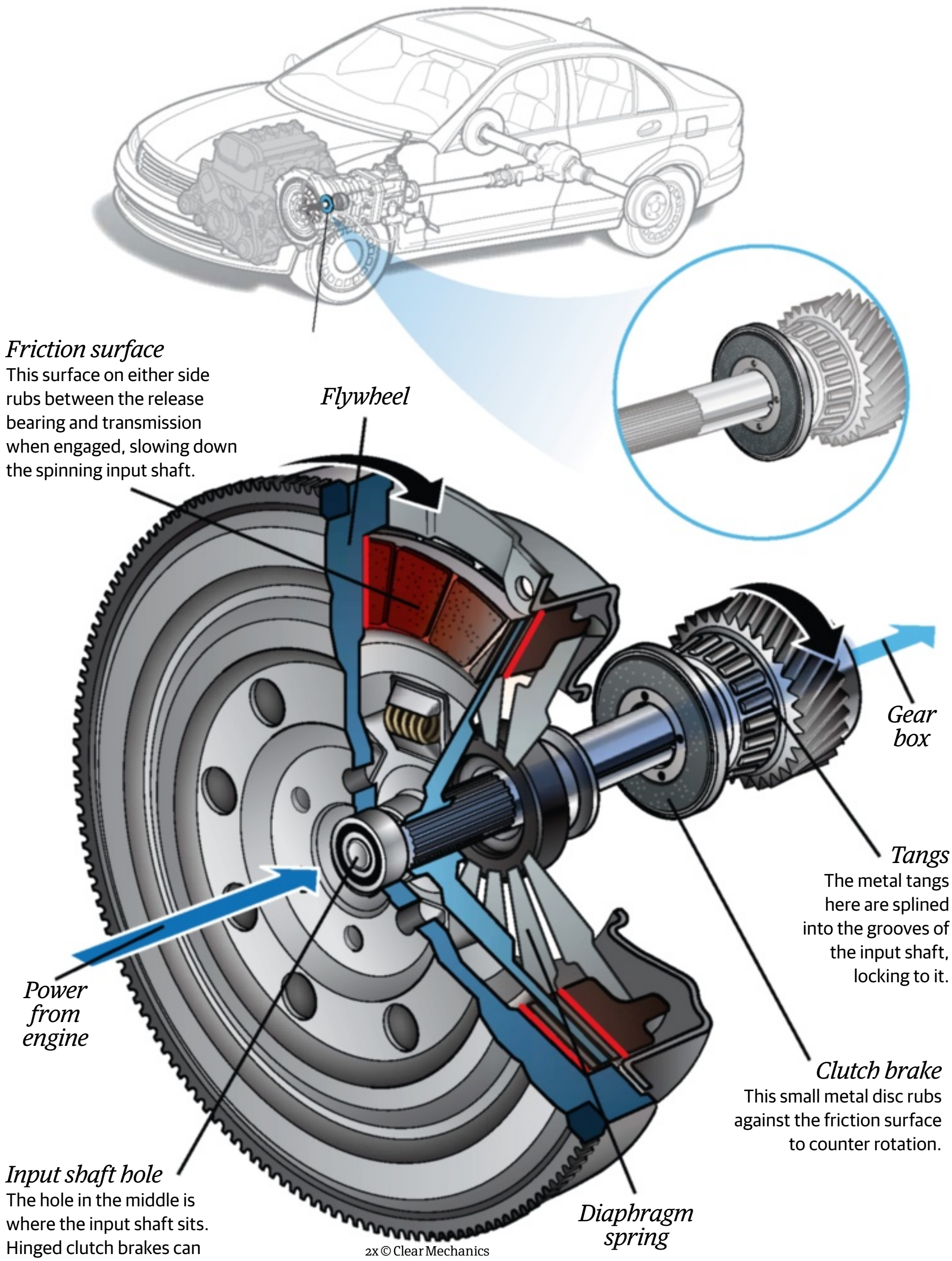
This metal ring is a vital element for most vehicles

Transmissions play a fundamental role in the process of moving a vehicle. A car's transmission is connected to the engine and serves to 'transmit' the power generated there to the wheels that drive it. Within this, gears reduce the number of revolutions of a crankshaft, ensuring more effective use of the engine's torque.

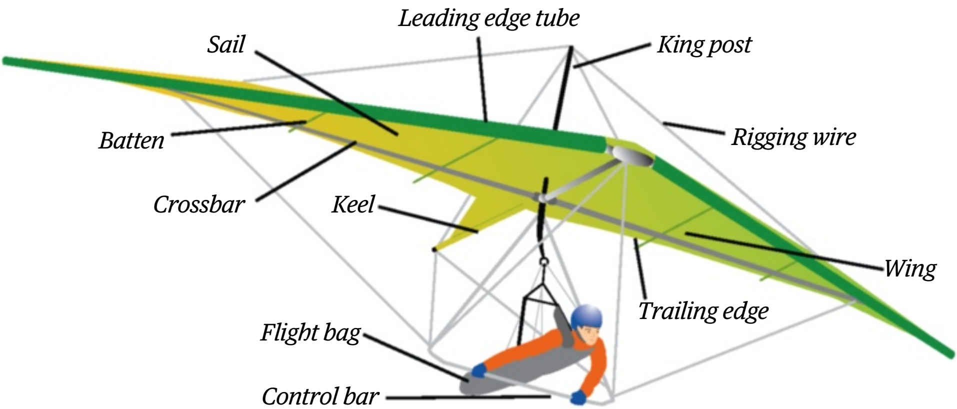
When a car is in neutral, power from the engine is driving the transmission input shaft, in turn rotating some parts in the transmission on idle. However, once first gear is selected to go forwards or reverse to go backwards, the clutch is depressed, disengaging the input shaft from the engine. Due to inertia, the input shaft could still spin for some time however, meaning certain parts of the transmission will be spinning too fast to interlock with the gears.

A clutch brake works by fixing to the input shaft on a manual gearbox, acting as a source of friction between the release bearing and transmission bearing retainer cap, reducing the input shaft's rate of rotation and slowing the spinning inside the gearbox. This allows for the gears to 'mesh' effectively without any significant grinding or clashing. Clutch brakes are instrumental in avoiding excessive wear of those all-important inner transmission components.

There are three common types of clutch brake found in vehicles: a one-piece clutch brake, a two-piece 'hinged' clutch brake and a torque-limiting clutch brake. The one-piece variety can only be installed with the transmission removed from the vehicle, so it can go over the circular input shaft. Its thick plate provides a good friction surface to slow the input shaft when it's spinning. A two-piece hinged clutch brake, on the other hand, can be installed with the transmission in place by hinging and then fixing around the input shaft. Finally, a torque-limiting clutch brake is used for more heavy-duty applications and features a hub with washers that slip under a certain amount of torque, ensuring the smooth engagement of gears in the transmission.



2x © Clear Mechanics



How do hang gliders fly?

Propelled solely by hot air, hang gliders make engineless flight possible

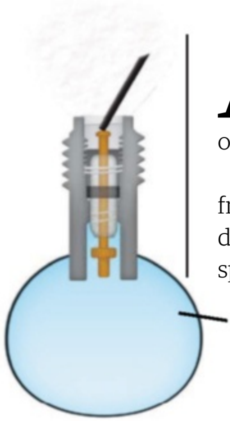
Hang gliders work by generating lift through their body and wing shape, as well as exploiting the natural meteorological updrafts created in Earth's atmosphere. Through this, they use gravity as a source of propulsion, yet stay airborne for lengthy periods of time The relationship between the amount of lift the glider is capable of and the amount of drag inflicted on it by the atmosphere's air molecules is key to its sustained flight, with the more metres of forward glide to every one metre of descent, the better.

When hang gliders were first invented, their heavy construction materials (wood and heavy metals) prevented pilots from achieving a good ratio. Today, however, super-lightweight carbon composite materials allow gliders to have significant glide ratios, usually over 15:1.

Construction consists of two parts, the control frame and the wings. The wings are designed to generate as much lift as possible as air passes over them, and maintain pitch and yaw equilibrium when gliding. The triangular control frame is attached to the centre of the wings; it provides a fixed platform for the pilot to be strapped to and shift within to alter course and altitude. Control is achieved by the pilot moving their weight fore or aft in opposition to the frame.

How do tyre valves work?

How valves keep air under pressure inside tyres



All tyres use a form of poppet valve, with the most common being the Schrader valve. This consists of a hollow cylindrical stem that has threading outside it. Running through the centre of the stem is a spring-loaded pin inside a sleeve.

A small disc that is located at the bottom of the pin prevents any air from escaping through the sleeve, and when the pin is then pushed down, air is then able to escape through the valve. The strength of the spring determines the pressure that is needed to push it open.

Valve open
When the pin at the centre of the valve is depressed, air will escape. An air pump has a centre pin that depresses the valve pin, allowing air to be pumped into the tyre.

How do boats brake?

What methods are used to slow a boat down?

Different boats use different ways to propel through water. For boats with propellers, the spinning propeller pushes water back and this pushes the boat forwards. You can slow them by stopping the propeller spinning. If you spin the propeller backwards, the boat will push water forwards and this will start to push the boat backwards and it will slow down a bit faster. An anchor is then used to keep the boat still.

© Wally

What's in a bulldozer?

Designed to demolish all in their path, discover what makes them so powerful

Key to how a bulldozer operates is its large powerful engine and tracks, which when combined allow the machine to push, pull and carry many-ton loads day in, day out, without seeming to struggle at all. This is because the tracks generate excellent ground hold and weight distribution, preventing the bulldozer from becoming stuck or slipping on difficult terrain. This ability, in partnership with the vast amount of torque generated by the vehicle's diesel engine and torque divider, allows substantial loads to be manipulated with ease – indeed, modern bulldozers can pull tanks that weigh over 70 tons!

A bulldozer consists of many different parts, but the three most noteworthy are its blade, tracks and ripper. Take a look at the animated image here to learn more about the essential components that make up the bulldozer.

Below
Some bulldozers sport wheels instead of tracks

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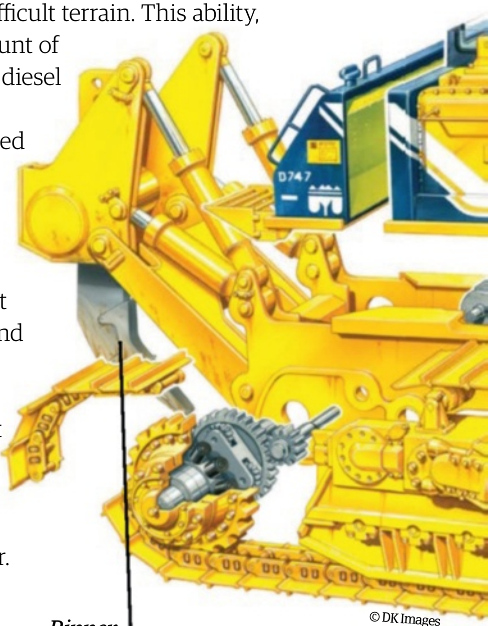


© DK Images

Ripper
A sharp metal-toothed feature that is driven into the ground by a hydraulic cylinder in order to break it up for easier excavation.

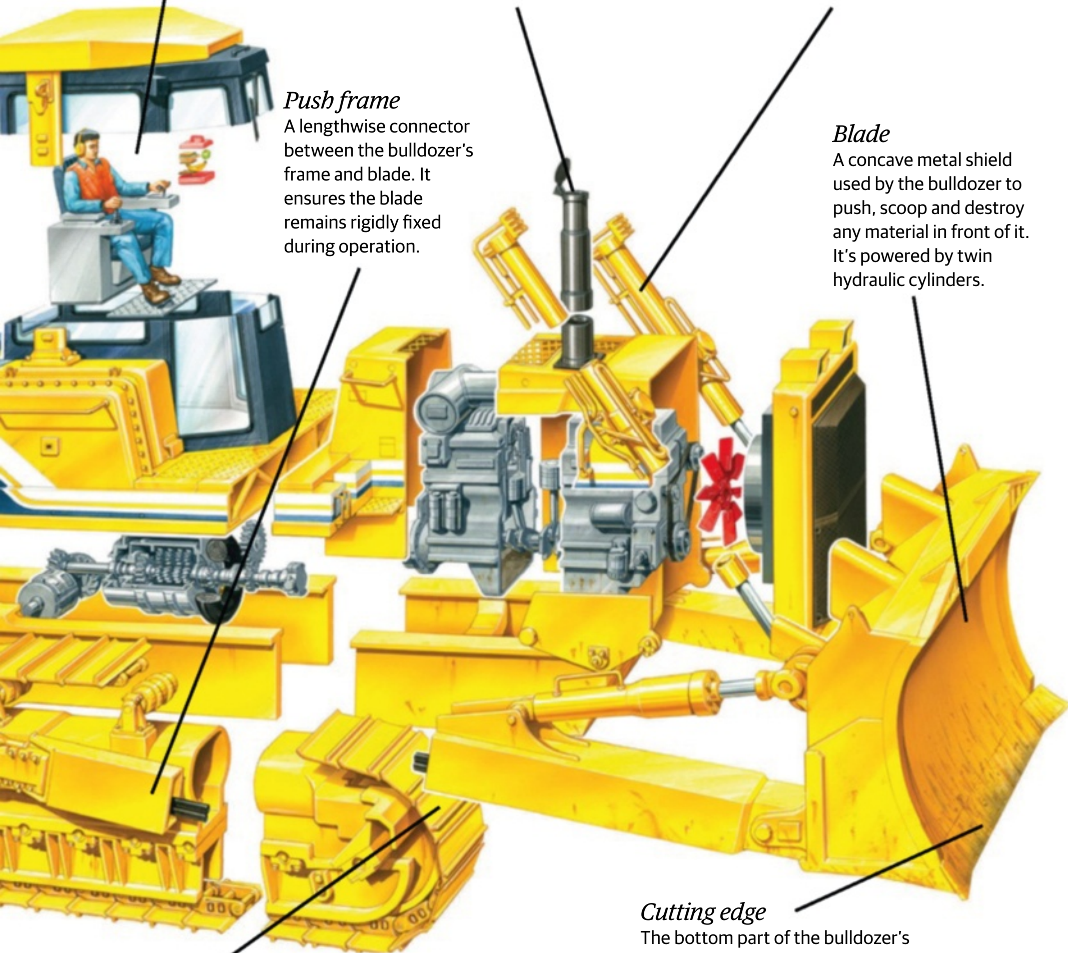
Cab
The command centre of the vehicle, the cab is the area where the driver sits and controls its movement, blade and ripper device.

Exhaust pipe
A large exhaust pipe through which the bulldozer's diesel engine can expel combustion gases.

Lift cylinder
One of two hydraulic lifting cylinders that allow the blade to lift vast quantities of excavated material

Push frame
A lengthwise connector between the bulldozer's frame and blade. It ensures the blade remains rigidly fixed during operation.

Blade
A concave metal shield used by the bulldozer to push, scoop and destroy any material in front of it. It's powered by twin hydraulic cylinders.



Cutting edge
The bottom part of the bulldozer's blade that makes frequent contact with the ground. Due to heavy wear, it's designed as a replaceable part.

Tracks
A linked array of metal plates that runs over a series of wheels, the tracks ensure the bulldozer generates maximum traction for pushing/pulling.

Why are London buses red?

The reason behind the choice of colour

In 1907, London operators still used a variety of colours to indicate where the bus was going. The largest operator, London General Omnibus Company, decided to make its buses stand out. It chose a spoked wheel as a symbol and the colour red for all its vehicles. When London Transport was eventually formed as a single company in 1933, red was already the predominant colour, so all buses in the Greater London area became red.

What are funicular railways?

Moving carriages up and down steep inclines

Funicular – or incline – railways are typified as two connected rail carriages running over a steeply inclined four, three or two-rail track. Both carriages are connected as they operate under the principle of counterweight. In order to overcome the lack of traction generated by steel rails and tram wheels, funicular railways use each of their pair of carriages to power and balance the other over a central, top-mounted pulley.

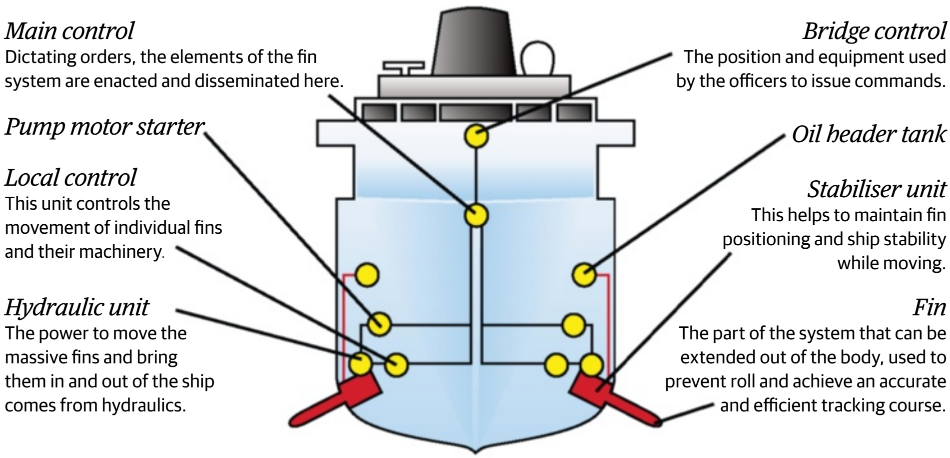
With this design, very little electrical power is required to haul many tons of carriage up a steep incline, with the only additional power needed to initialise the pulley's motor. The pulley provides enough force to overcome the difference in weight between the carriages (ie passengers) as well as counteract any friction between the two forces.

How do ships stay level?

Stabilisers are the secrets behind sailing straight in rough waters

Ship stabilisers come in three main categories: bilge keels, ship stabilisers and gyroscopic ship stabilisers. Bilge keels are long thin strips of metal that run in a 'V' shape along the length of a ship at the turn of the bilge (the area on the outer surface of a ship's hull where the bottom curves meet the vertical sides). Bilge keels work by dampening a ship's roll capability by counteracting roll pressure with physical hydrodynamic resistance. Ship stabilisers differ to bilge keels in shape and positioning, resembling fins rather than gills and are often positioned in pairs at the stern and bow of a ship. They do, however, work in the same way and are usually positioned on the bilge in line with the ship's bilge keel. Due to their larger size and protrusion, ship stabilisers offer greater resistance to ship roll but negatively affect its manoeuvrability and increase its hull clearances when docking.

Gyroscopic ship stabilisers are complex fin systems that can be incrementally adjusted in their angle of attack (a vector representing the relative motion between lifting body and the fluid through which it is moving) to counteract roll, and brought in and out of the hull at will thanks to specially tailored hydraulic mechanisms.



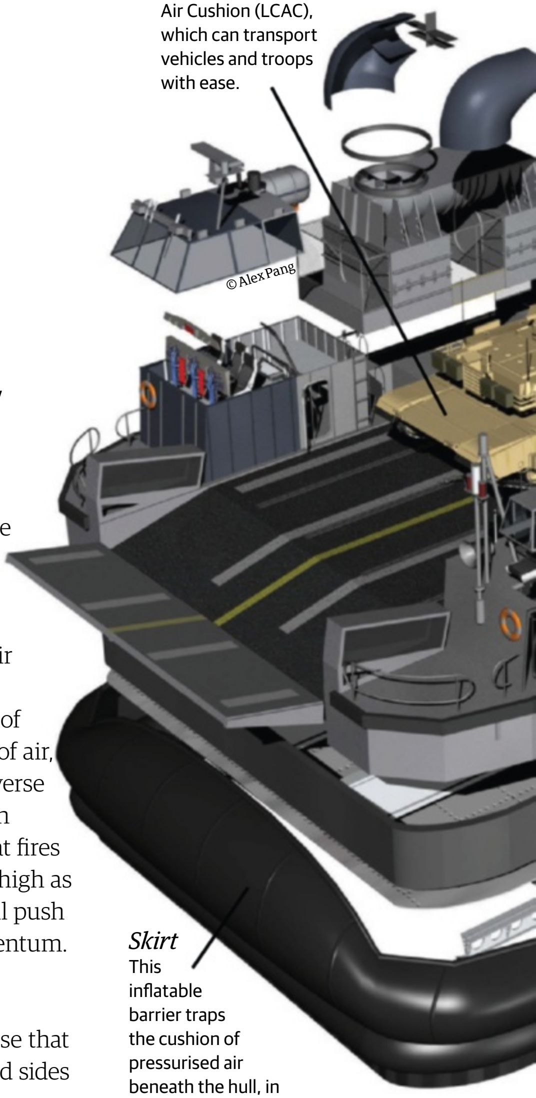
How does a hovercraft hover?

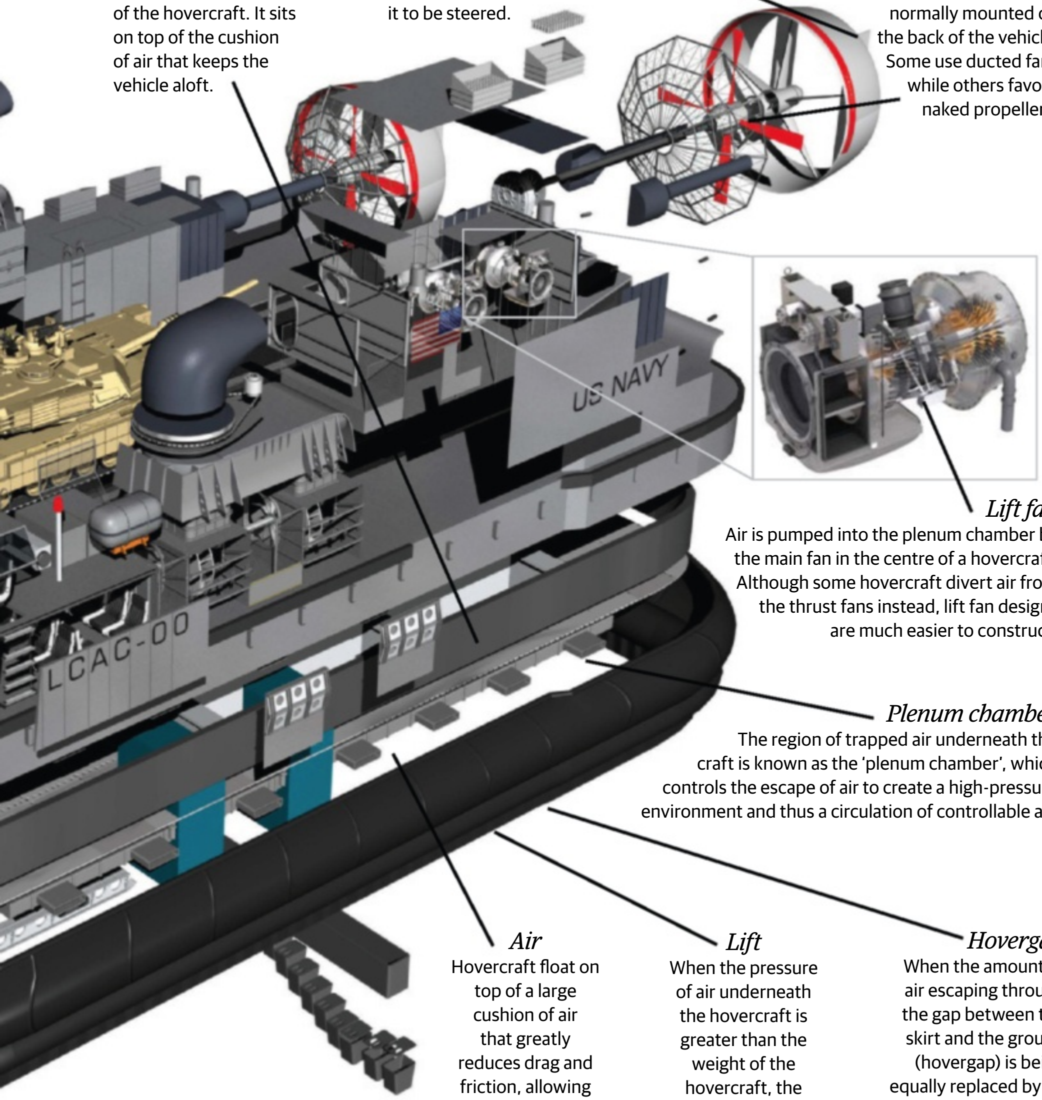
Why can these machines traverse both land and sea

The ability of hovercraft to cross dry land as well as water has seen them employed in the military and tourism sectors for many years. Although once billed as the next generation of transportation, they have somewhat decreased in popularity over the last decade. Despite this, their usefulness is still readily apparent.

The core principle of a hovercraft is that the hull of the vehicle is suspended on top of a giant cushion of air, held in place by flexible rubber that allows it to traverse difficult terrain or choppy waves without being torn apart. At the centre of a hovercraft is a huge fan that fires air downwards, pushing the hull off the ground as high as two metres (6.5 feet). Smaller fans on top of the hull push air backwards, giving the hovercraft forward momentum. Rudders direct this flow of horizontal air to allow a hovercraft to change its direction.

Traditional hovercraft have an entirely rubber base that allows for travel on land or sea, but others have rigid sides that, while suited only to water, can have propellers or water-jet engines attached for a quieter craft.





Hull

The hull is where you'll find the driver, passengers and cargo of the hovercraft. It sits on top of the cushion of air that keeps the vehicle aloft.

Rudders

Flaps at the back control the hovercraft like an aircraft, directing airflow in certain directions to allow it to be steered.

Thrust fans

The hovercraft gains its propulsion from these backwards-facing fans, normally mounted on the back of the vehicle. Some use ducted fans while others favour naked propellers.

Lift fan

Air is pumped into the plenum chamber by the main fan in the centre of a hovercraft. Although some hovercraft divert air from the thrust fans instead, lift fan designs are much easier to construct.

Plenum chamber

The region of trapped air underneath the craft is known as the 'plenum chamber', which controls the escape of air to create a high-pressure environment and thus a circulation of controllable air.

Air

Hovercraft float on top of a large cushion of air that greatly reduces drag and friction, allowing the vehicle to travel over almost any terrain.

Lift

When the pressure of air underneath the hovercraft is greater than the weight of the hovercraft, the vehicle will rise up to a height of a few metres.

Hovergap

When the amount of air escaping through the gap between the skirt and the ground (hovergap) is being equally replaced by air from the lift fan, the hovercraft is at its maximum height.

Rudder
Due to their great length, sprint kayaks can be fitted with a small rudder to aid turning, which is controlled by the paddler's feet.

Chassis
Modern kayak chassis are constructed from carbon fibre, fibreglass or wood. This ensures a light weight and therefore higher speed.

Beam
The beam, or widest part, of a kayak, is rarely much wider than the kayaker's width. This greatly reduces the drag experienced by the kayak.

How do kayaks stay afloat in rough waters?

A look inside these versatile boats

Kayaks are small, narrow boats – most commonly single-seater – designed to transport their user over a variety of watery environments, be that calm, flat lakes, choppy coastal waters or torrential river rapids. Due to their ability to traverse such varied terrains, kayaks can take many forms. For example, racing kayaks are long and narrow – often exceeding six metres (19 feet) in length – to reduce drag and maximise the distance per stroke generated by the paddler's oar. On the other hand, white-water kayaks are short and squat, often measuring in at no more than 1.5 metres (five feet) as stability and the ability to turn sharply are the key requirements when navigating jagged rocks and steep drops.

Indeed, when you consider this rather diverse usage, it won't come as a surprise to discover that there are over six main categories of kayak, including: recreational, oceanic, white-water, racing, surf and hybrid types.

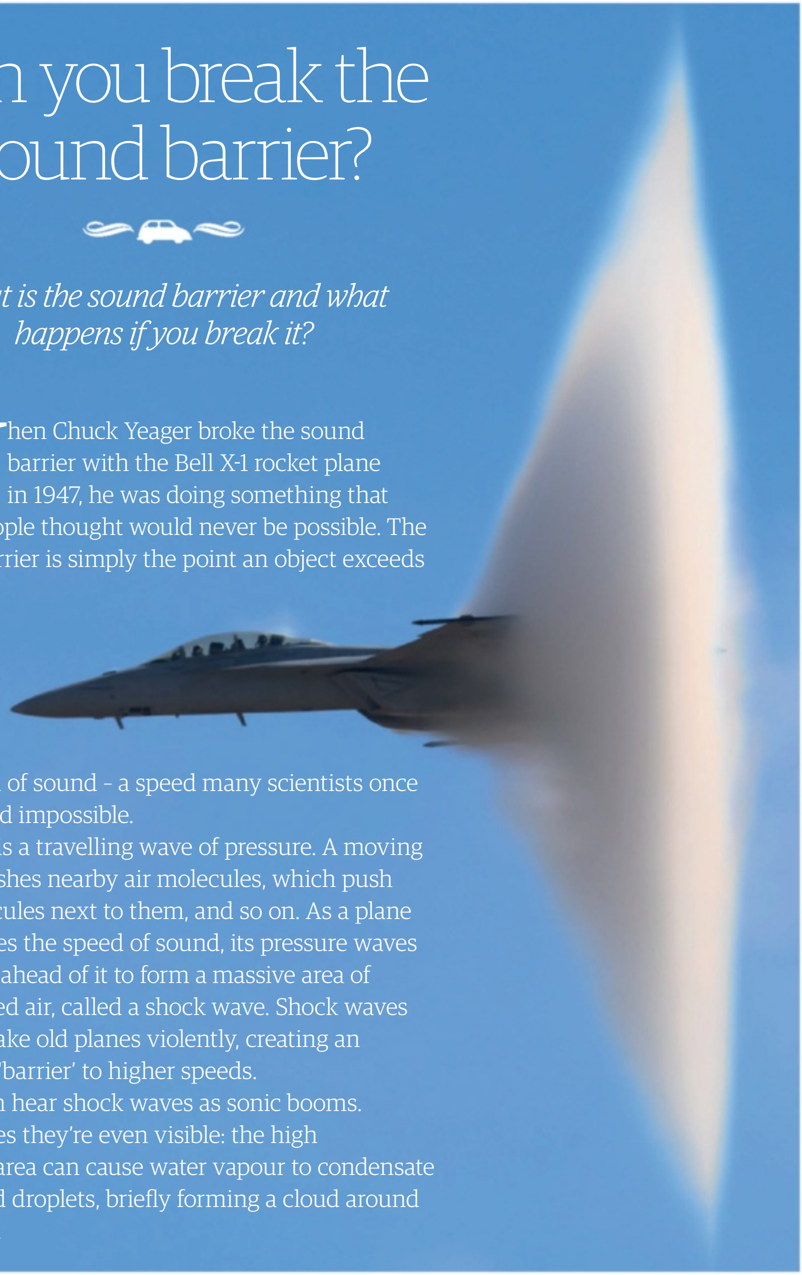
Can you break the sound barrier?

What is the sound barrier and what happens if you break it?

When Chuck Yeager broke the sound barrier with the Bell X-1 rocket plane in 1947, he was doing something that many people thought would never be possible. The sound barrier is simply the point an object exceeds the speed of sound – a speed many scientists once considered impossible.

Sound is a travelling wave of pressure. A moving object pushes nearby air molecules, which push the molecules next to them, and so on. As a plane approaches the speed of sound, its pressure waves 'stack up' ahead of it to form a massive area of pressurised air, called a shock wave. Shock waves would shake old planes violently, creating an apparent 'barrier' to higher speeds.

You can hear shock waves as sonic booms. Sometimes they're even visible: the high pressure area can cause water vapour to condensate into liquid droplets, briefly forming a cloud around the plane.



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How does an aircraft carry weaponry?

Finding space to turn planes into deadly weapons

Hardpoints, also commonly referred to as weapon stations, are any part of an aircraft's airframe that has been designed to carry an external load. These loads commonly involve additional weaponry, fuel or other forms of countermeasures, the latter usually consisting of braces of flares.

There are three main types of hardpoint, each with its own unique advantages and disadvantages. The first type is rail launchers, which are used to carry and launch large missiles and rockets. These comprise thin narrow rails mounted under an aircraft's fuselage, to which missiles are attached by a basic slot mount. These rail systems work by simply dropping the missile on command from the mount, with the weapon then propelling itself clear of the plane under the power of its own ignited engine and kinetic energy.

Ejector racks make up the second type of hardpoint, although technically speaking the rack is not a hardpoint but is attached to one via a pylon. Ejector racks consist of braces of free-fall bombs and small rockets in a close-knit array hung beneath a plane's wings. The positioning of the rack away from the wing surface ensures that control surfaces are not disrupted. The ejector racks also work by physically pushing the bomb/missile free, this time using explosive cartridges, which when engaged destroy the rack's weapon hooks. To make sure the primed weapon is definitely released, each rack is equipped with both primary and secondary charges, as a backup.

The third station is the wet hardpoint. These are referred to as 'wet' as they are plumbed and capable of interfacing with drop tanks mounted on them. This allows an aircraft to carry extra stores of fuel outside of its primary reservoir, supplementing its maximum combat range. Importantly, despite their connection to the aircraft's fuel tank, wet hardpoints can still be jettisoned when empty to reduce weight and drag, and also be used to mount additional weaponry if needed.


Pylons
Ejector racks or single missiles can be mounted to an aircraft via underwing pylons, which provide clearance for additional, or larger, munitions.
Rails
Rail launchers are commonly fitted under the fuselage of a fighter jet, dropping missiles free-fall prior to rocket ignition.
Swing
Fixed-wing aircraft can mount weapons under their wings and on their tips, something not possible with swing-wing aircraft.

How do snowmobiles work?

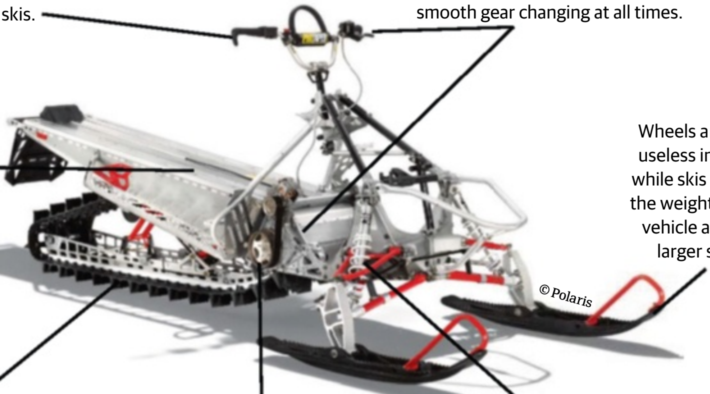
Read on to find out how these vehicles traverse icy terrain

In the pursuit of getting from A to B as quickly as possible, it was only a matter of time before traditional skis were replaced when traversing snow and ice, and the snowmobile invented. The roots for this snowy-terrain vehicle are in military technology, where the rubber in the off-road tracks was proven to work even in adverse winter conditions.

A Canadian inventor called Joseph Armand Bombardier took the design, adapted and refined it to create the first single-passenger snowmobile in 1959: the Ski-Doo. Bombardier Industries has gone on to be a leader in the snowmobile market, while the snowmobile itself has become the de facto standard for fast travel across ice and snow-dominated landscapes.

Handlebars
Tanks and construction vehicles use variable track speeds to steer, while snowmobiles use the handlebars to turn the skis.

Clutch
The engine uses a primary and secondary clutch system to ensure smooth gear changing at all times.



Skis
Wheels are near useless in snow, while skis spread the weight of the vehicle across a larger surface area.

Chassis
A snowmobile chassis needs to be as strong and as light as possible: this model is just over 180kg (400lb).

Tracks
The 38cm (15in)-wide tracks are similar to those on tanks, except made of rubber or aluminium. They can be equipped with studs too, for extra traction.

Engine
A similar design to engines found in jetskis, it has a large gear mechanism that turns the tracks.

Shock absorbers
This component has improved through the decades. Shocks not only help you maintain control but also make the ride much more comfortable.

What are decoy flares?

Confusing missiles to avoid destruction

Decoy flares work by generating a heat signature in excess of the launch vehicle's jet engines. This has the effect of confusing any incoming heat-seeking missile's homing system into locking on to the flares' signatures instead of the aircraft's, causing it to explode at a safe distance and saving the pilot's life. There are two main types of countermeasure flare – pyrophoric and pyrotechnic. The former is activated automatically on contact with air and the latter by the mechanical removal of a friction cap prior to firing. The composition of either type of flare is often tailored to counter specific missile systems or to mimic the launch jet's heat signature.

What's inside a medieval castle?

The stereotypical fairy tale castle design was actually the result of centuries of improvement upon existing structures

Left
Dover Castle in Kent, UK, was founded in the 12th century and still stands today

Below
The 12-meter-high walls of Ávila, Spain, contain several castles as well as the town

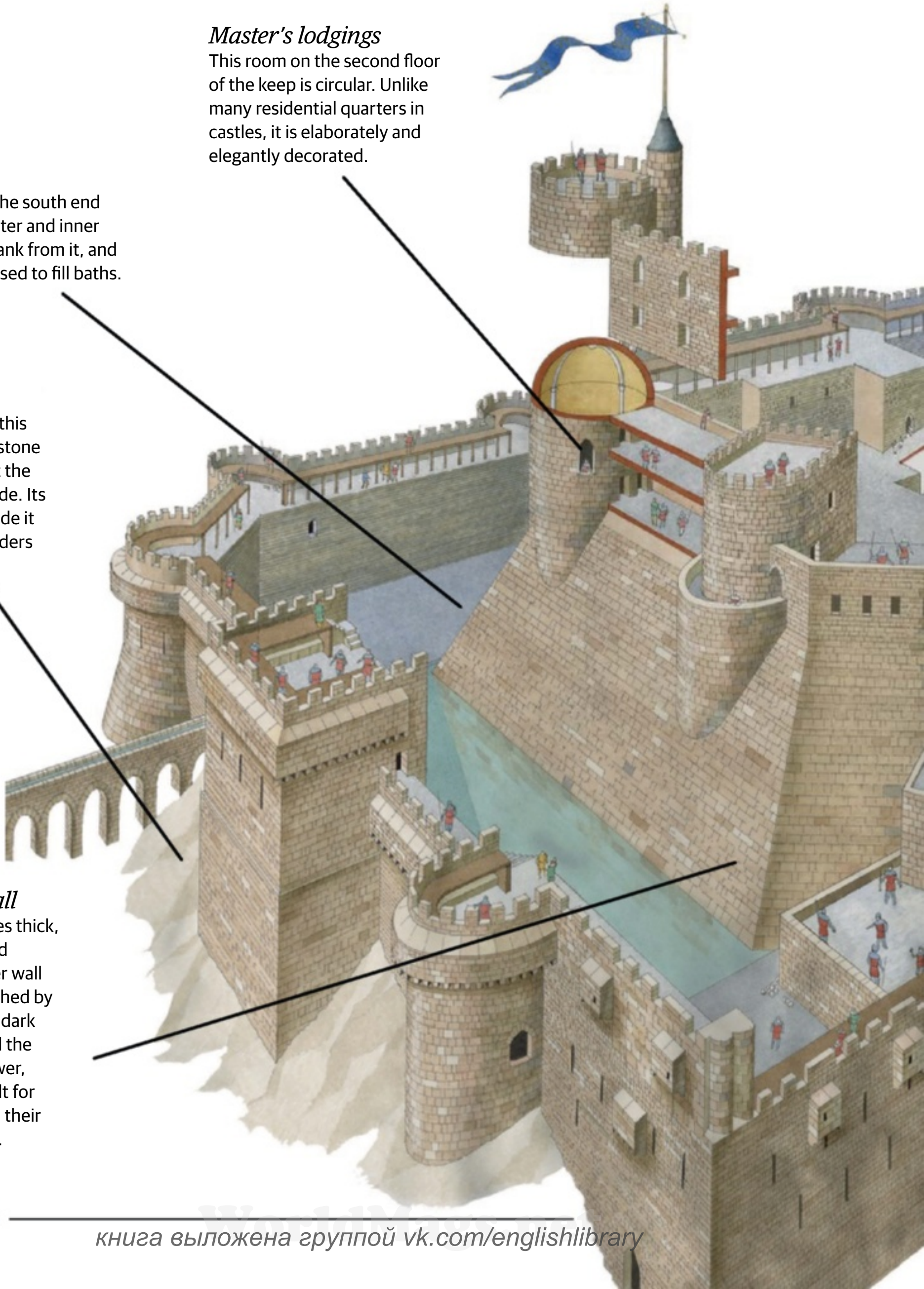
Medieval castles were an important part of feudal society. They began to appear around 1066 AD with the invasion of William the Conqueror. As he moved through England, Scotland and Wales, William had more than 30 castles built to help maintain power over his newly conquered lands.

These castles served as bases for lords who held land from the king and pledged loyalty and military service to him in return. These lords leased parts of their land to lesser lords and barons, who had knights that served under them.

These imposing structures had multiple functions. Castles were bases of offensive operations, defensive strongholds, seats of government and private residences for land-holding barons, knights and lords and their families. Most were built in stages over long periods of time and modified as greater defences were needed. Although their structures varied, they generally consisted of a tall building in the centre, which could function as a residence, prison or storage area, surrounded by one or more walls. Some castles were built on a mountain or hilltop, or on the edges of cliffs, to make invasion that little bit more difficult.

Medieval castles

We examine the components of Krak des Chevaliers



Master's lodgings

This room on the second floor of the keep is circular. Unlike many residential quarters in castles, it is elaborately and elegantly decorated.

Moat

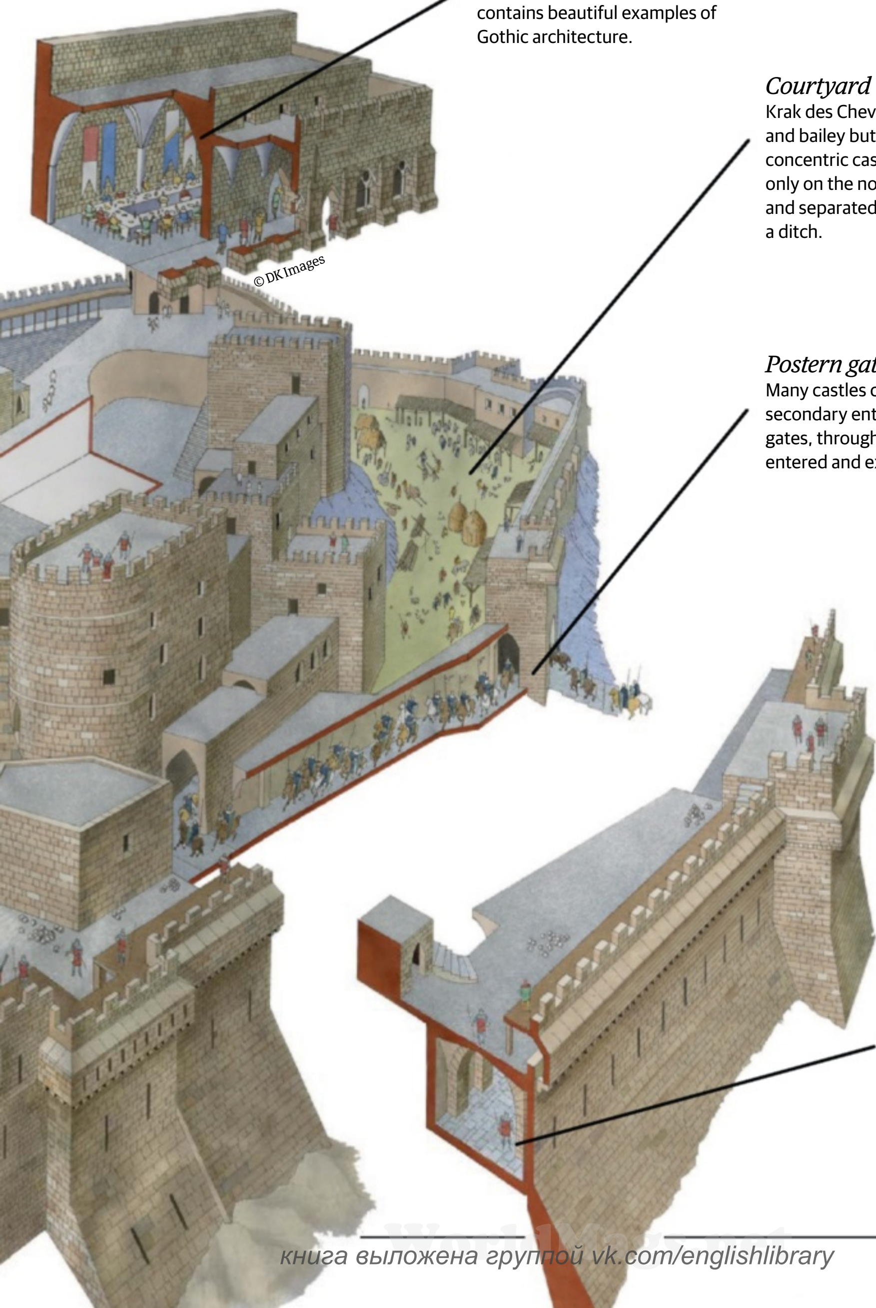
This moat is at the south end between the outer and inner wall. Horses drank from it, and the water was used to fill baths.

Stone slope

Crusaders built this 24-metre thick stone slope to protect the castle's south side. Its smoothness made it difficult for invaders to scale.

The inner wall

Up to four metres thick, with seven guard towers, the inner wall can only be reached by going through a dark passageway and the great square tower, making it difficult for intruders to find their way to the keep.



Great hall

The large hall to the left of the courtyard was used for banquets, meetings and receptions. It contains beautiful examples of Gothic architecture.

Courtyard

Krak des Chevaliers began as a motte and bailey but was upgraded to a concentric castle. The courtyard is only on the north side of the castle and separated from the outer wall by a ditch.

Postern gate

Many castles contained one or more secondary entrances, or postern gates, through which its residents entered and exited.

Outer wall

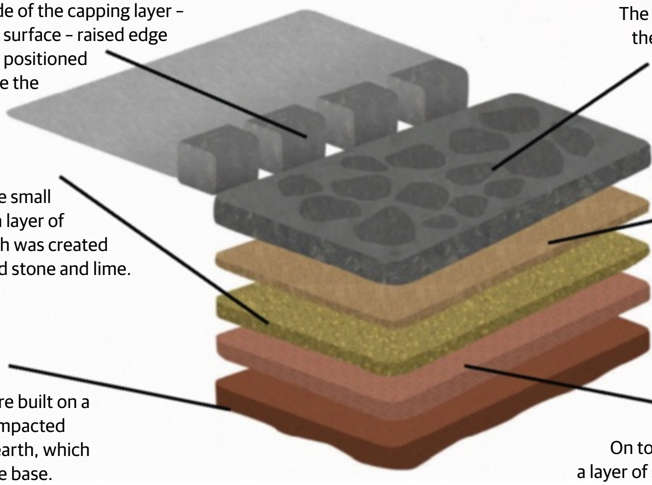
The outer wall of Krak de Chevaliers, a 12th century castle built in Syria, is three to five meters thick with 13 guard towers.

How were Roman roads built?

How were these ancient highways made, and were they always straight?

While the concept of roads had existed for hundreds of years prior to the Romans, it was through the Roman Republic's – and later Roman Empire's – widespread use of them throughout Italy and beyond that most of ancient Europe became so well connected. In addition, they contributed heavily to the spread of the territories under Roman control as they enabled troops, supplies and traders to quickly travel from place to place.

Roman road construction was heavily institutionalised, with set materials and designs. Roads were of a certain width and depth, consisting of a number of layers built up from a pre-dug trench. The roads were also split up, depending on their size, ownership and purpose. For example, viae publicae were large main roads, maintained through public taxation, while viae privatae were funded and built by private individuals. While Roman construction rules did indicate roads should be built straight wherever it was possible, this was not in practice typical, with only major high roads built that way.



6. Edge
On either side of the capping layer – ie the road's surface – raised edge stones were positioned to demarcate the pavements.

5. Lava
The four previous layers were then capped with polygonal blocks of basaltic lava or a similar hard stone.

3. Rubble
On top of the small stones was a layer of rubble, which was created from crushed stone and lime.

4. Lime
A bedding of pounded pot shards and lime was then deposited over the rubble and compressed.

1. Earth
All roads were built on a level and compacted expanse of earth, which served as the base.

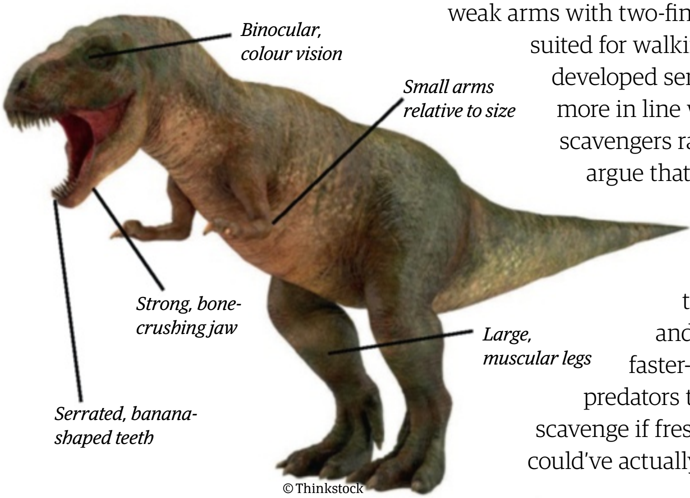
2. Stones
On top of the earth was placed a layer of small, compacted stones.

How did T-rex hunt its prey?

The T-rex may have been one of the largest meat-eating dinosaurs, but it might not have been a predator at all

Tyrannosaurus rex – from Greek and Latin words meaning 'tyrant', 'lizard' and 'king' – was one of the largest carnivorous dinosaurs to walk the earth. Likely prey included the Triceratops horridus and the Torosaurus, each about the size of an elephant. There have been several nearly complete Tyrannosaurus rex skeletons found since the first bones were discovered in 1894, some of which included soft tissue. From these, palaeontologists have learned that the T-rex had a lot of bird-like traits. It likely had a one-way air sac system that kept its lungs constantly full of fresh air, hollow bones to lighten its body weight, and binocular, colour sight. It also had a wishbone, or furcula. Some palaeontologists believe that our assumptions of scaly, lizard-like skin might not be entirely accurate and that T-rex could've even had feathers.

Controversy about the T-rex centres on whether it was a predator or a scavenger, as well as whether it moved slowly or quickly. Many palaeontologists believe that the Tyrannosaurus rex was strictly a predator, but those who question this assumption point to its short, weak arms with two-fingered hands, large legs suited for walking distances and a strongly developed sense of smell. These seem more in line with what we know of scavengers rather than predators. Others argue that muscle scars found on skeletons show that the T-rex had strong arms. They also believe that their binocular sight and hollow bones indicate a faster-moving predator. However, predators today will sometimes scavenge if fresh prey isn't around, so T-rex could've actually been both.



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How was Pompeii destroyed?

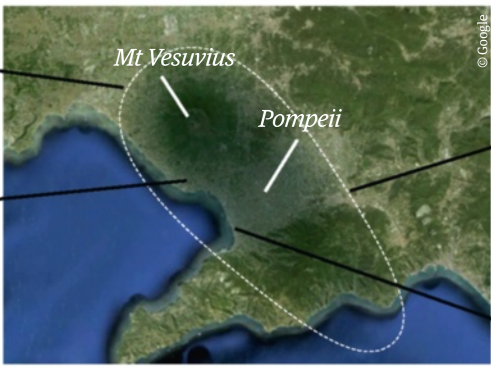
When Mount Vesuvius erupted in 79 CE, it wiped the city of Pompeii off the face of the planet

Pompeii was a medium-sized Roman city in the Italian region of Campania. In 79 CE, however, it was completely destroyed in the eruption of nearby Mount Vesuvius, a stratovolcano located close to the city of Naples.

The destruction of Pompeii (and other cities; see below) was caused according to stratigraphic studies in two main phases. The first phase was a Plinian eruption, which is typified by a colossal ejection of gas and volcanic ash high into the stratosphere. This phase lasted roughly 20 hours and produced a rain of pumice in a southwards-reaching cone that stretched for over 32 kilometres (20 miles).

The second – and for the people of Pompeii, even more deadly – phase was a Peléan eruption, which consisted of a number of vast pyroclastic flows. These flows were fast-moving currents of superheated gas (at roughly 1,000 degrees Celsius/1,800 degrees

Below
While Pompeii bore the brunt, a wide region around Mount Vesuvius suffered disastrous consequences of the eruption



Herculaneum
While escaping much of the initial eruption, Herculaneum was destroyed when Vesuvius's eruptive column collapsed.

Oplontis
A smaller settlement, Oplontis was also buried deep under layers of tephra. There were fewer casualties, however, due to its coastal position.

Nuceria
One of the largest and most wealthy towns in the area, Nuceria survived the eruption largely intact, only receiving the diluted edge of the largest surge.

Stabiae
At 16km (9.9mi) from Vesuvius, Stabiae only received roughly 2m (6.6ft) of ash over six pyroclastic surges. Nevertheless, its port was annihilated.

Fahrenheit) and rock that rapidly dispersed at ground level into the surrounding area. The combination of both these phases led to the burning and asphyxiation of all life that stood in harm's way.

In addition, the eruption caused a small tsunami in the nearby Bay of Naples, rendering escape attempts by boat impossible, and a series of tremors that aided the destruction of dwellings and temples.

Today, over a thousand casts have been made from impressions of bodies trapped in Vesuvius's ash and flow deposits discovered in and around Pompeii, along with various other scattered remains. Out of the total found, 38 per cent were discovered in ash fall, with the remaining 62 per cent found in surge deposits. Unfortunately, due to a lack of official documentation from the time, what percentage these represent of Pompeii's total population is unknown.

Since the eruption of 79 CE, Vesuvius has erupted more than 30 times, the last occurring in March 1944. Despite this, the area surrounding Mount Vesuvius continues to be lived in by many Italians, with the entire region in its immediate vicinity colonised. To combat the potential for disaster, the Italian government foresees the need for an emergency evacuation of over 600,000 people and has marked a 'Red Zone' for those areas that would be most affected.

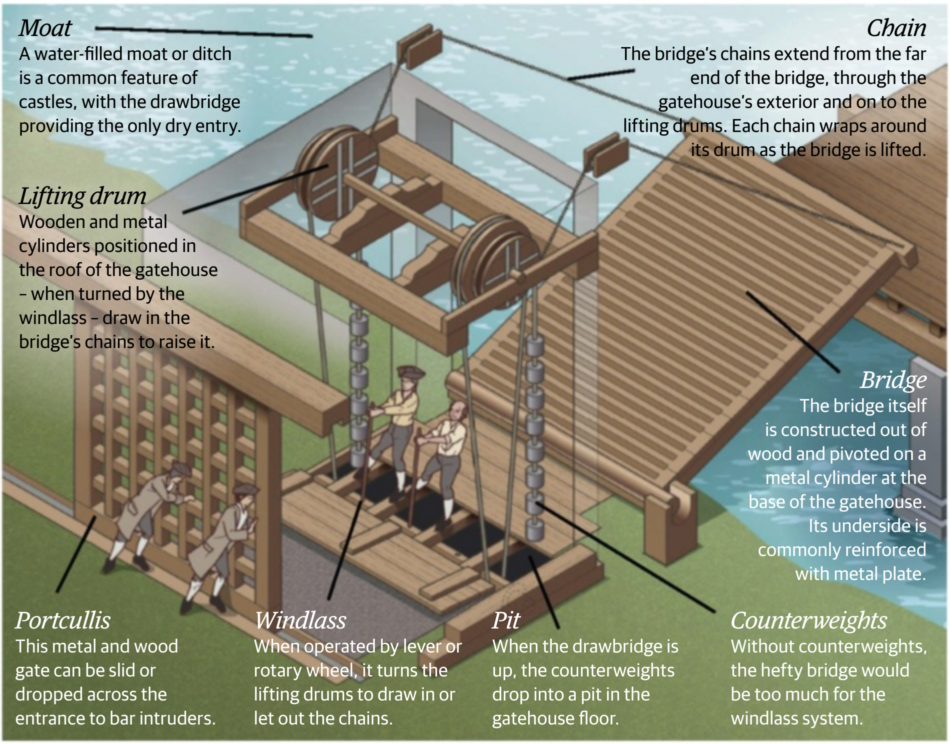
Below
Mount Vesuvius as seen today from above

Inset, Below
A body cast of a victim from Pompeii. This person was in a crouched position holding his hands over his nose and mouth when he died

How did drawbridges work?

These fold-up entrances were simple yet effective

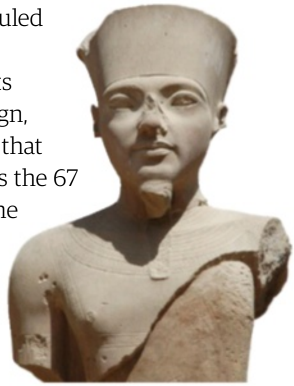
Classical drawbridges worked via the principle of counterweight, with large wood and metal bridges pivoted via a series of balancing weights in a castle's gatehouse. The weights, which were attached to the bridge's lifting chains, enabled the platform to be raised via a windlass, which in turn rotated a pair of lifting drums that gathered in the chains. By employing counterweights, heavy bridges could be operated by just a few people. Along with a moat, a reinforced drawbridge served as a two-fold barrier, making it much more difficult for any enemies to invade a fortification or city.



Which pharaoh ruled the longest?

Who ruled over Ancient Egypt for the longest time?

According to later king lists, Pepi II ruled for 94 years around 2200 BCE. However, contemporary documents only go up to the seventh decade of his reign, and it is not certain that he really ruled for that long. The longest fully documented reign is the 67 years of Rameses II, who came to the throne in 1279 BCE and built more temples than any other pharaoh. The next place is a tie between Thutmose III (1479 BCE) and Psamtik I (664 BCE), both of whom ruled for 54 years.



Right
Many pharaohs had longer reigns than today's monarchs

When was the Rialto Bridge built?

It's an instantly recognisable landmark, but when was it built?

The Rialto Bridge is one of only four bridges that span the Grand Canal in Venice, Italy. It was commissioned in the late-16th century to replace the previous wooden structure, which was prone to collapse. Blueprints were submitted by the most eminent architects of Renaissance Italy, including Michelangelo, but the commission ended up going to the relatively unknown Antonio da Ponte in 1588, whose revolutionary design featuring a single broad arch was completed in 1591. Today, the Rialto Bridge is one of the most visited tourist sites in the city.

Why does the Tower of Pisa lean?

Find out how the tower was made, how it went wrong, and how it continues to stay standing

The local architects and city officials designed the complex at Piazza dei Miracoli (the Square of Miracles) as a dedication to art, and as such it is thought the principles of science and engineering were not fully understood.

The tower was built in three stages over a period stretching nearly two centuries. The first part of the tower was built during a time of town prosperity and as such heavy white marble was used for the base and tower, with limestone used for the interior and exterior design features.

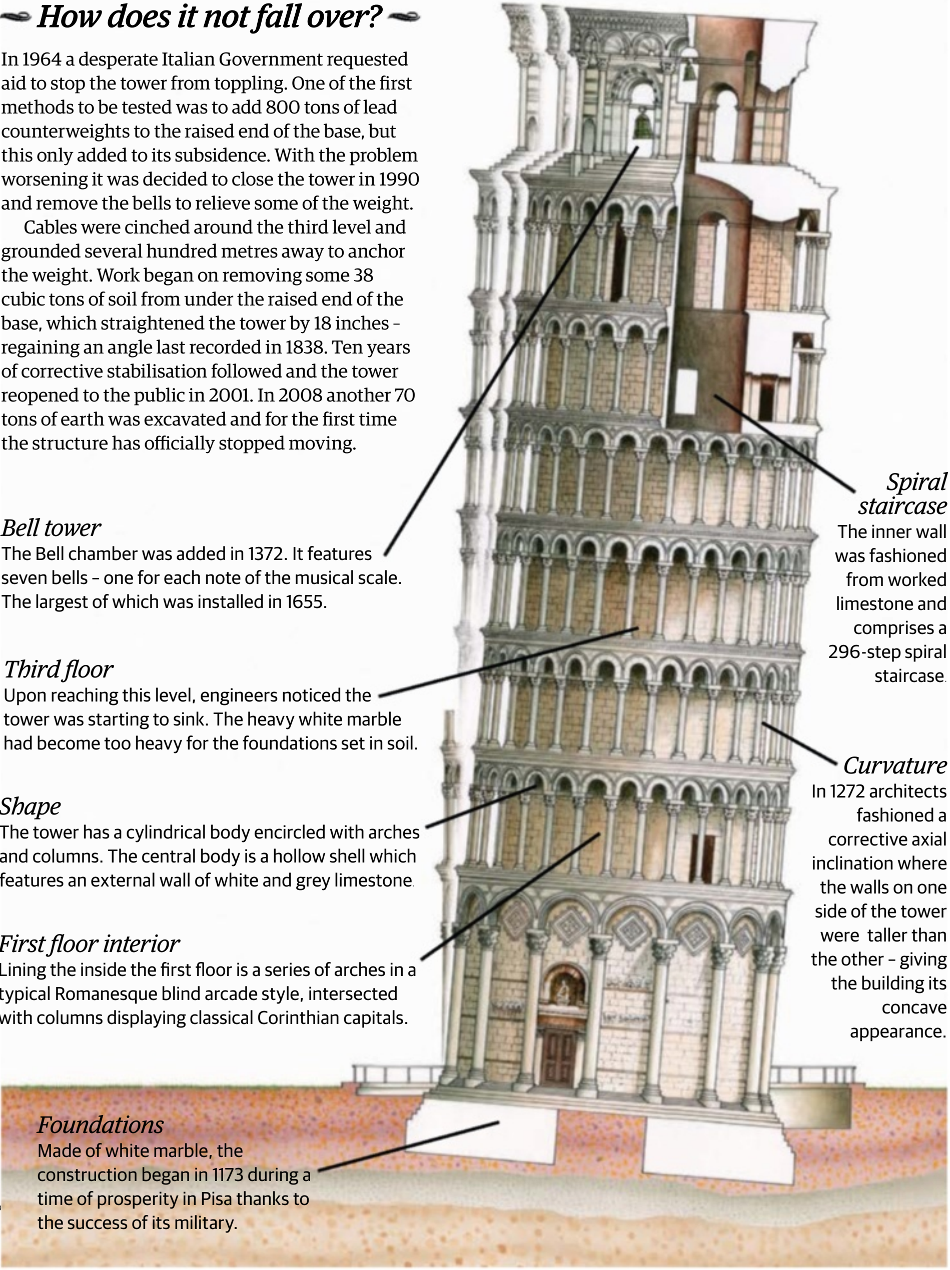
Disaster occurred just five years after work began, as the workers finalised the interior of the third floor. The tower was sinking because the weight of the marble building was too much for the extremely insufficient three-metre foundations which had been set in weak and unstable soil that contained a malleable mixture of clay, sand and rubble. The construction was halted for nearly a century to allow the soil to settle. In 1272 work recommenced as engineers began to build the tower's middle section.

To compensate for the continuing problem of its lean, the workers built one side of the wall taller than the other. Subsequently the tower began to lean in the opposite direction and caused it to curve. War caused a break in construction and the seventh floor was not completed until 1319 and the eighth level, featuring the belfry, was finally added in 1372.

How does it not fall over?

In 1964 a desperate Italian Government requested aid to stop the tower from toppling. One of the first methods to be tested was to add 800 tons of lead counterweights to the raised end of the base, but this only added to its subsidence. With the problem worsening it was decided to close the tower in 1990 and remove the bells to relieve some of the weight.

Cables were cinched around the third level and grounded several hundred metres away to anchor the weight. Work began on removing some 38 cubic tons of soil from under the raised end of the base, which straightened the tower by 18 inches – regaining an angle last recorded in 1838. Ten years of corrective stabilisation followed and the tower reopened to the public in 2001. In 2008 another 70 tons of earth was excavated and for the first time the structure has officially stopped moving.



Bell tower
The Bell chamber was added in 1372. It features seven bells – one for each note of the musical scale. The largest of which was installed in 1655.

Third floor
Upon reaching this level, engineers noticed the tower was starting to sink. The heavy white marble had become too heavy for the foundations set in soil.

Shape
The tower has a cylindrical body encircled with arches and columns. The central body is a hollow shell which features an external wall of white and grey limestone.

First floor interior
Lining the inside the first floor is a series of arches in a typical Romanesque blind arcade style, intersected with columns displaying classical Corinthian capitals.

Foundations
Made of white marble, the construction began in 1173 during a time of prosperity in Pisa thanks to the success of its military.

Spiral staircase
The inner wall was fashioned from worked limestone and comprises a 296-step spiral staircase.

Curvature
In 1272 architects fashioned a corrective axial inclination where the walls on one side of the tower were taller than the other – giving the building its concave appearance.

How long were sabre-toothed tigers' teeth?

© Walace63

A look at this extinct animal's defining features

Sabre-toothed tigers were actually sabre-toothed cats, or smilodons, which lived mainly in the Americas and became extinct about 10,000 years ago. Their teeth were between 18-28cm (7-11in) long. It's believed smilodons used their teeth on subdued prey to cut off the blood supply and strangle them. Despite the larger teeth, they had a weaker bite than modern-day big cats but could open their jaws 120 degrees compared to lions whose limit is 60.

What's the biggest excavation site?

The archeological site that's larger than Luxembourg

The prehistoric site of Çatalhöyük in Turkey covers about 13 hectares (32 acres), while the Palace of Knossos, Crete, covered an area of about 13,000 square metres (140,000 square feet). Pompeii covers an area of 60 hectares (145 acres) and has been described as 'the most complete urban excavation ever undertaken'. This is tiny in comparison to the ruins of the temple complex of Angkor Wat in Cambodia, which cover up to 3,000 square kilometres (1,160 square miles)!

© Ziggurat

Right
The ruins of the temple complex of Angkor Wat in Cambodia covers up to 1,160 square miles

How was pottery made?

A look at the potter's wheel – a revolutionary device in ceramics

The potter's wheel enabled us to easily create round ceramic wares such as pots and gourds. The machine worked by supplying the potter with a rotating circular platform upon which, via hand moulding, clay could be shaped as desired. The rotation was provided by a large kick wheel, which once set in motion – the potter literally kicked it, hence the name – supplied energy to a smaller modelling wheel, which sat above on a metal shaft. As the kick wheel was much bigger than the modelling wheel, it acted as a flywheel, storing rotational energy that could be used to power the modelling plate, which due to its smaller circumference, span at a greater speed.

Thanks to its ease of use, the potter's wheel remained the method of choice for making pottery for many millennia, eventually evolving to be driven by a motor.

Modelling wheel
The potter shapes the clay material on this plate, which rotates at high speed while they model the object.

Tools
While pots are moulded with the hands, a number of small tools help the potter make incisions and add decoration.

Wheel shaft
Both wheels are connected through the centre of the wooden frame by a metal shaft.

Kick wheel
The potter kicks this wheel to start it rotating. It acts as a flywheel, storing energy and forcing the connected modelling plate to spin at high speed.

Frame
The wooden frame provides support for both the wheels and a surface for the potter to work on.

What caused the Ice Ages?

Why the Earth's temperature plummeted

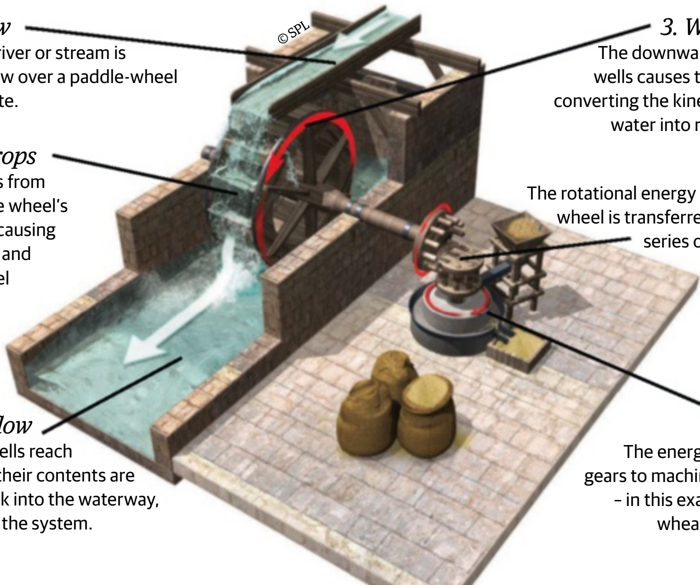
It's likely that a combination of changes to atmospheric composition, the Earth's orbit and ocean currents are responsible for these periods of low temperatures. Many experts link the onset of ice ages to falling levels of greenhouse gases. Variations in Earth's orbit around the Sun also play a role, controlling how much solar energy the planet receives and affecting temperatures. Finally, the shifting of tectonic plates has a knock-on effect on ocean and wind currents, which have an important influence on Earth's climate.

How did water mills work?

How did these ancient systems harness the power of water to perform a variety of tasks?

Water mills were – and in rare circumstances still are – facilities in which moving water was used as the driving force to power a milling apparatus. The key component in a water mill was a waterwheel, although in later times turbines were also employed, which converted the kinetic and potential energy of water into rotational mechanical energy to drive various machines. Most commonly the mill would grind grain to produce flour.

Historically there have been different types of water mill, each largely determined by the type of wheel they used. The kind of wheel chosen was dictated by the local geography and the source of water, with rivers on flat plains requiring an undershot waterwheel, while those dropping from elevated positions allowing for more efficient designs, like overshot wheels. Today, water mills are used far less due to the availability of more efficient energy-production systems; however, some mills still operate for demonstrative purposes.



1. Input flow
Water from a river or stream is diverted to flow over a paddle-wheel through a chute.

2. Water drops
The water falls from height into the wheel's slatted wells, causing them to fill up and push the wheel downwards.

3. Wheel rotation
The downwards motion of the wells causes the wheel to turn, converting the kinetic energy of the water into rotational energy.

4. Cogs
The rotational energy generated by the wheel is transferred to the mill via a series of cogs and gears.

5. Mill
The energy is carried by the gears to machinery inside, which – in this example – is grinding wheat to produce flour.

6. Output flow
As the filled wells reach ground level, their contents are deposited back into the waterway, flowing out of the system.

Who were the musketeers?

They fought in battles and protected esteemed rulers all the way from France to India

Musketeers were an early form of soldier who were armed with muskets. They acted as a bridge unit between traditional infantry and dragoons, a type of light cavalry armed with long-ranged weapons. This granted them a level of versatility and flexibility most prized on the battlefield, with musketeer units typically reserved for the protection of nobility or royalty.

While musketeers as a unit are older, they didn't emerge in Europe until the 16th century, with the concept only really taking off on a large scale in the early-17th century. While this particular era was dominated by the French musketeers of the Maison du Roi (the Royal Household) – upon which the fictional musketeers of Dumas's The Three Musketeers are based – Spain, Britain, Russia, Sweden, Poland and even India each developed their own musketeer units in this period and used them on the battlefield.

Musketeers as a common military unit were largely phased out by the middle of the 19th century, with developments in firearms rendering the musket obsolete. With the introduction of the rifle – which could shoot both farther and much faster than the musket – the rifleman unit could emerge, negating the need for the greater speed of the mounted musketeer. This, combined with the decline of many dynasties throughout Europe – like the Ancien Régime of France – saw all musketeer units permanently disbanded.

Below
A Prussian engraving of a French musketeer (right) from the reign of Louis XIV (1643-1715)

© Ian Jackson

Bandolier
Bandoliers (a pocketed belt) and ammunition pouches/bags were a common accessory for musketeers, so they were always well supplied on the battlefield. These belts were strapped around the waist or chest.

Hat
Musketeers started off in the West wearing simply ornate hats, but by the early-19th century these evolved into metal helmets. They did remain decorative though, often with large feathered plumes attached.

Musket
The musketeer's primary weapon, the musket was deadly albeit cumbersome to use. Its slow reload rate restricted use to four shots per minute at best.

Cape
A feature associated more with earlier iterations of musketeers, the cape offered some protection from the elements while travelling.

Holdall
As musketeers were on the road during much of their military service, each carried their own holdall to store food and personal belongings.

Tunic
Considerably more elaborate than standard infantry, musketeer tunics and – in later periods – cuirasses, favoured manoeuvrability over armoured protection.

Sword
As musketeers were trained to fight both on horseback like dragoons and on foot like infantry, they were also equipped with a sword for hand-to-hand engagements.

Boots
Boots were an important part ofthe musketeer's uniform, both communicating their prestigious position and providing good support on the ground and on horseback (some had spurs attached).

Who wrote the Magna Carta?

Learn about this famous medieval document

The Magna Carta, or Great Charter, is an English medieval document drawn up in 1215 by King John's barons in feudal times. The barons were tired of having a king who could punish according to whim and the Magna Carta was a document that sought to curtail this power and give every freeman (non-serf) certain rights.

King John signed the document, although his intent was simply to bring the barons over to his side, as civil war was brewing and Prince Louis of France was threatening to invade. He had no intention of honouring the document. But after King John's death in October 1216, the Magna Carta was copied and frequently used to show the sovereign was bound by law. Indeed, it has proved to be one of the most important civil rights movements in British history.

A 1297 copy of the Magna Carta has been preserved by the National Archives Conservation Lab by putting it in a case filled with the noble gas argon to prevent damage from oxidation. The case itself was hollowed out of a 15-centimetre (six-inch) block of aluminium in order to reduce creases through which the gas might leak.

Below (left)
King John signed the Magna Carta, although didn't intend to honour it

Below (right)
Salisbury Cathedral houses one of the four original copies

© Getty

What is the Terracotta Army?

The truth behind these mysterious figures

The Terracotta Army, unearthed in 1974, is one of the most exciting archaeological finds in recent history. The figures represent the soldiers of Qin Shi Huang, the first emperor of China. They had been placed in his tomb, an earthen pyramid mound, which was excavated beneath Mount Li. Construction had begun when the emperor was a child - it took many years to build. The tomb represents the royal palace, and the figures inside, court residents. Beside the warriors, archaeologists found models of officials and entertainers. There are 8,000 soldiers, each depicted with weapons such as spears, bows and arrows. There are also models of horses and chariots. Made out of yellow clay, the Terracotta Warriors were meant to protect the emperor in the afterlife. Artisans first made the limbs and heads which were then fired in a kiln. Once assembled, the models were painted and coated with a preservative, but only some colours are still visible. Each figure was given individual features, with details added to the hair and clothes; artists even added muscle tone to the arms and legs. The height of the soldier depended on his rank - ie the military generals are the tallest figures in the group.

Above
Figures of soldiers, officials and entertainers made up the Army

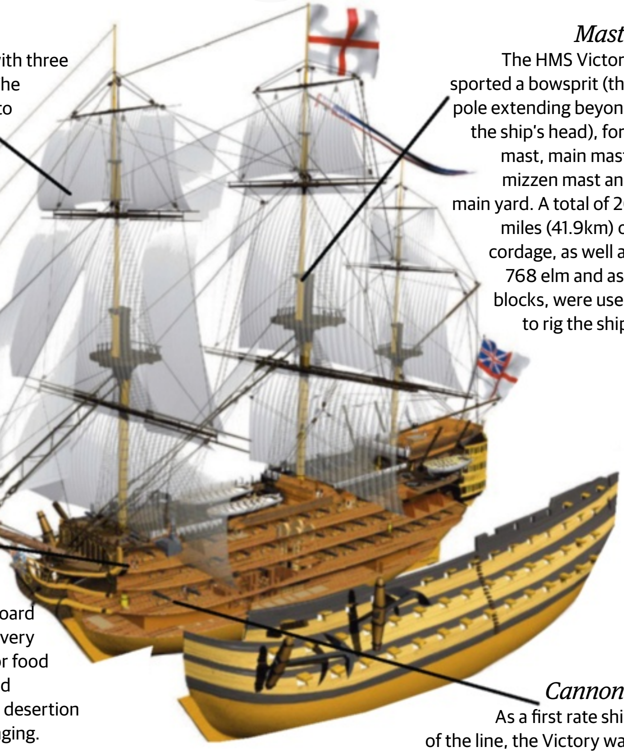
What's inside HMS Victory?

One of the most famous ships of all time, HMS Victory was crucial to ensuring British naval supremacy during the late 18th and early 19th centuries

The only surviving warship to have fought in the American War of Independence, the French Revolutionary War and the Napoleonic wars, the HMS Victory is one of the most famous ships ever to be built. An imposing first rate ship of the line – line warfare is characterised by two lines of opposing vessels attempting to outmanoeuvre each other in order to bring their broadside cannons into best range and angle – the Victory was an oceanic behemoth, fitted with three massive gundecks, 104 multiple-ton cannons, a cavernous magazine and a crew of over 800. It was a vessel capable of blowing even the largest enemy vessels out of the water with magnificent ferocity and range, while also outrunning and outmanoeuvring other aggressors.

Historically, it was also to be Vice-Admiral Horatio Lord Nelson's flagship during the epic naval battle off the Cape of Trafalgar, where it partook in the last great line-based conflict of the age, one in which it helped to grant Nelson a decisive victory over the French and Spanish but at the cost of his own life.

Below
Turner's famous painting of the Battle of Trafalgar in which the HMS Victory is shown in the midst of battle



Sails
The HMS Victory is a fully rigged ship, with three sets of square sails covering 5,440m². The breadth of the Victory's sails allowed it to sport a top speed of nine knots when operational, which was for the time very impressive considering its size. During the 18th and 19th centuries a fully rigged ship necessitated three or more masts each of which with square rigging.

Masts
The HMS Victory sported a bowsprit (the pole extending beyond the ship's head), fore mast, main mast, mizzen mast and main yard. A total of 26 miles (41.9km) of cordage, as well as 768 elm and ash blocks, were used to rig the ship.

Crew
There were over 800 people on board the HMS Victory, including gunners, marines, warrant officers and powder monkeys among many others. Life on board was hard for the sailors, who were paid very little for their services and received poor food and little water. Disease was rife too, and punishments for drunkenness, fighting, desertion and mutiny ranged from flogging to hanging.

Cannons
As a first rate ship of the line, the Victory was a three-gundeck warship with over 100 guns In fact, the Victory was fitted with 104 cannons: 30 x 2.75 ton long pattern 32-pounders on the gundeck, 28 x 2.5 ton long 12-pounders on the middle gundeck, 30 x 1.7 ton short 12-pounders on the upper gundeck, 12 x 1.7 ton short 12-pounders on the quarterdeck, and 2 x medium 12-pounders and 2 x 68-pounder carronades on the forecastle.

A ship's decks

The quarterdeck
The nerve centre of the ship, where its commander dictated its manoeuvres and actions.

The poop deck
Located at the stern, this short deck takes its name from the Latin word puppis, which literally means 'after deck' or 'rear deck'. This deck was used for signalling, but also gave some protection to the man helming the ship's wheel.

©Alex Pang

The gundecks
Housed most of the cannons, with a tiered arrangement from top to bottom (largest on the bottom).

The orlop
A storage area and habitation deck for certain crew members like the purser.

The hull
The largest storage area where up to six months of food & drink could be stored.

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